Recent Results on Smoke from Diesels and Cars

California Inspection and Maintenance Review Committee

October 26, 2005

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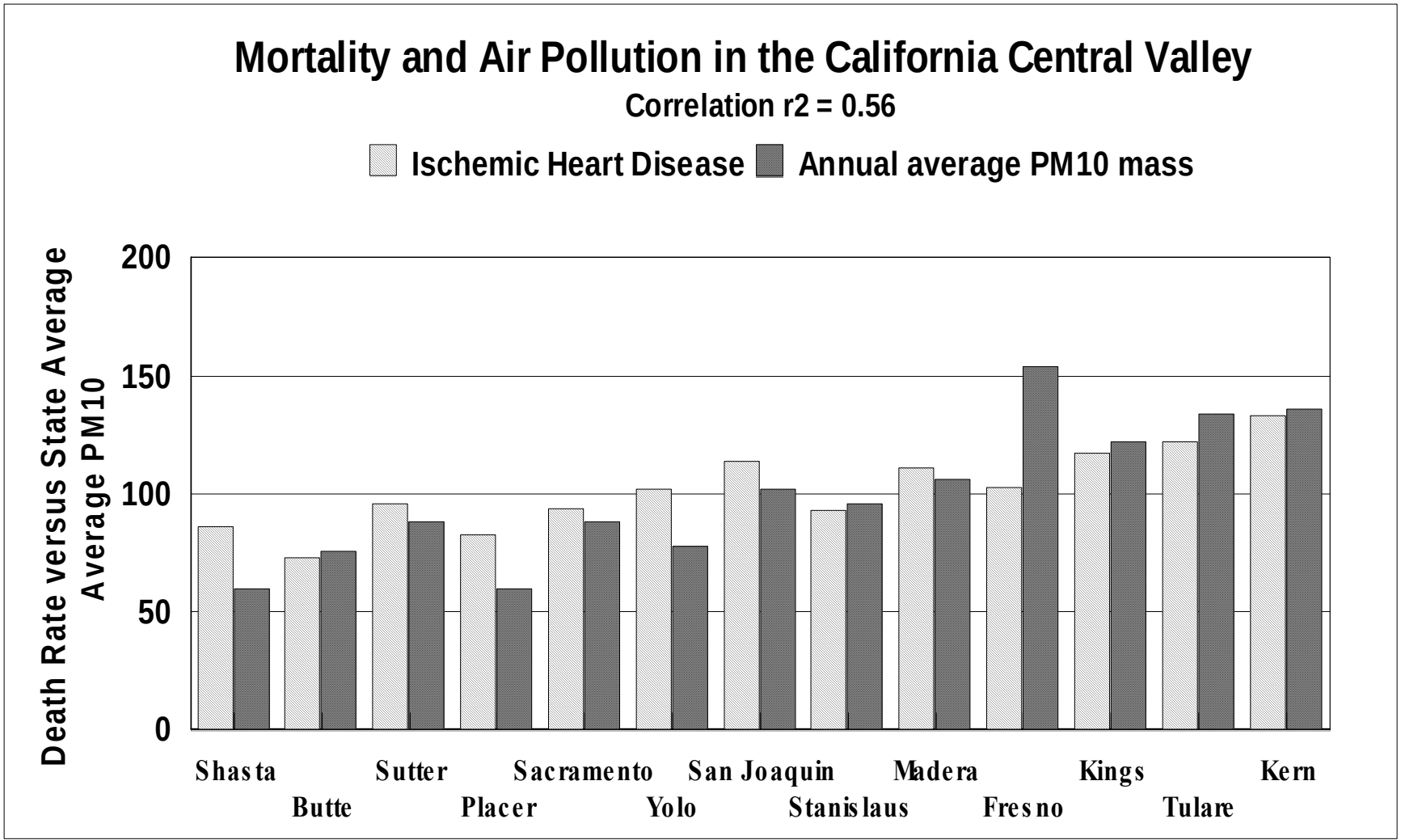
The heart disease death rate in the Central Valley correlates best with particles in the atmosphere



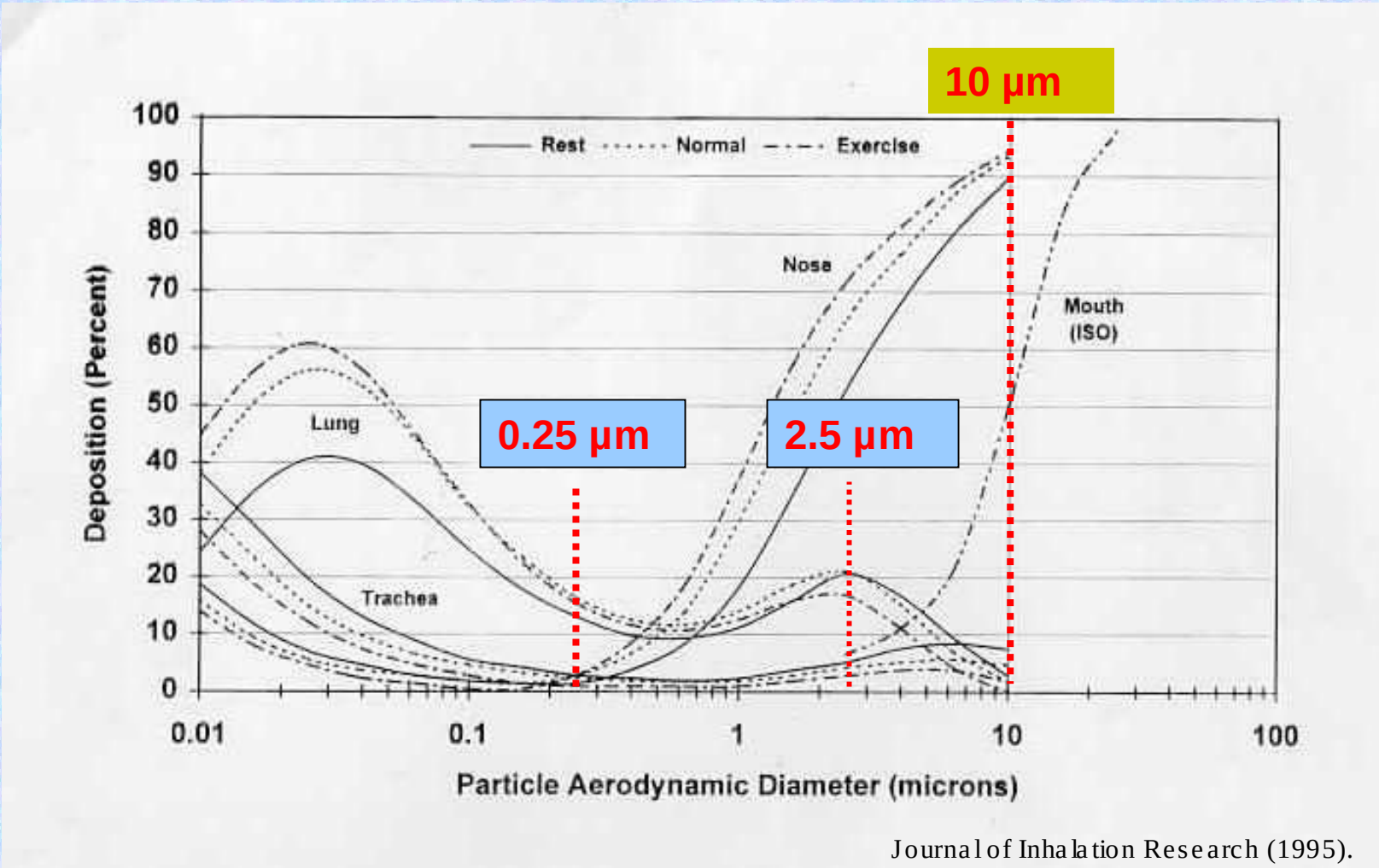
Health impacts of particles -

The causality behind the strong statistical associations

- Most fine particle mass is harmless!
- Summary of Bob Devlin, US EPA (AAAR, 2003) – top 5 suspects the for bad effects
  - Biological aerosols – evidence strengthening
  - Acidic aerosols – evidence weakening
  - Fine transition metals – effect of iron, etc.
  - Ultra-fine insoluble particles- any composition
  - High temperature organic matter – diesel/cars

Diesels and smoking cars

Particle Size versus Percent Deposition



Journal of Inhalation Research (1995).

This figure shows the relationship between particle size and what percent is deposited in different parts of the respiratory tract.

Sources of information – joint studies with the DELTA Group

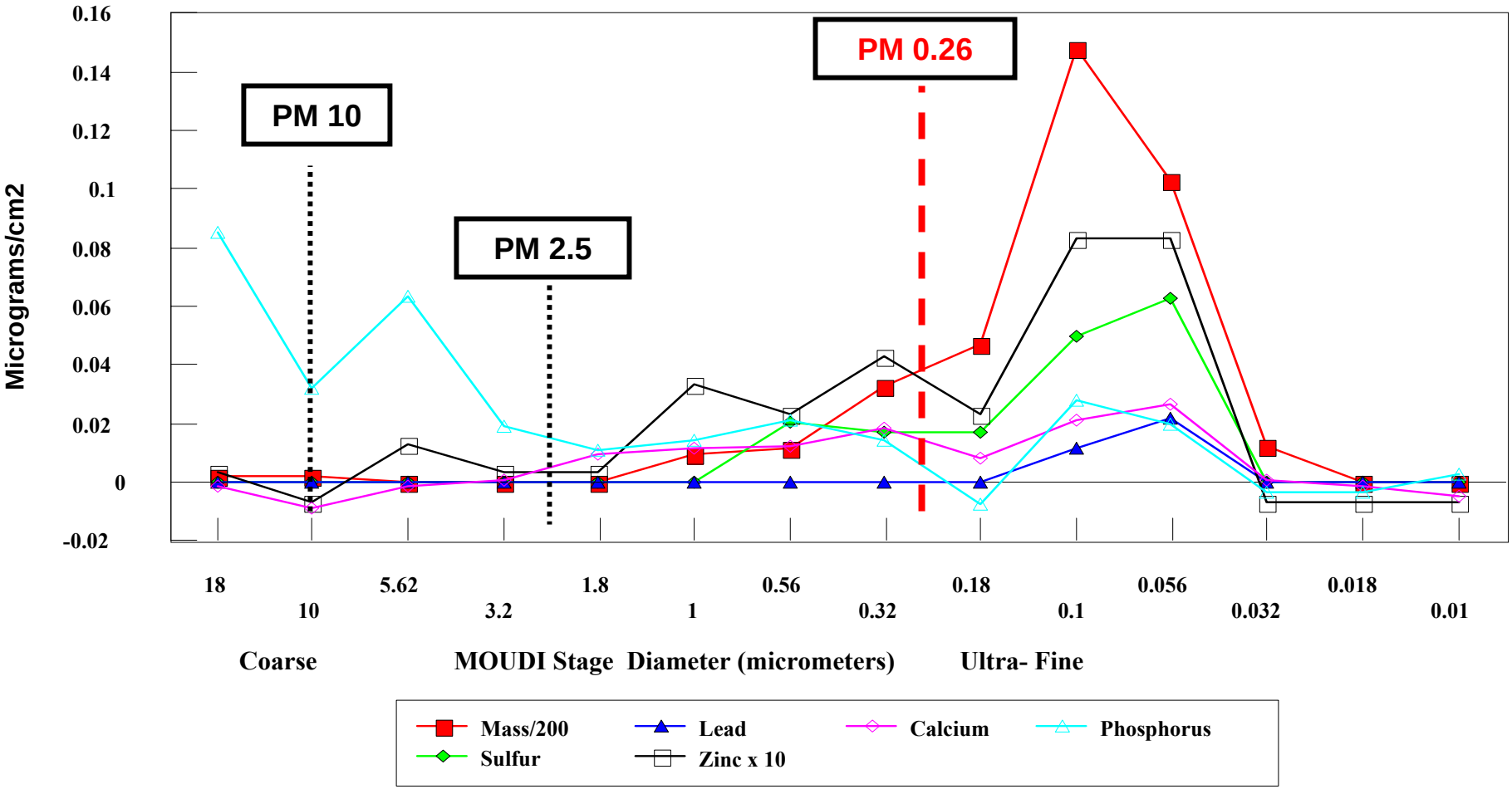
- **Laboratory studies** – NREL/U. Minnesota/DRI diesels; UCD S-XRF analysis –(Lawson, Watts, Zielenska et al.), plus DRI Lube oil (Fujita)
- **Prior field studies** – prior ARB/UC Davis work (1972-1978) ; HEI/DRI Tuscarora Tunnel (Gertler et al 2002)
- **Quasi-ambient and ambient applications**
  - Interstate 5 on downtown Sacramento and Watt Ave School – (Lung Assoc – Sacramento Emigrant Trails)
  - Fresno FACES studies (ARB)
  - UCLA/USC Los Angeles data
  - World Trade Center smolder phase

Diesels and all compression ignition (CI) engines

- An inherently dirty technology
  - High compression and temperature fixes NO
  - High molecular weight fuel makes toxic organics
  - Close tolerances make effective cylinder lubrication difficult – burned lubricating oil
- Post combustion clean up effective but expensive
  - The role of small versus large diesel engines
  - The role of short haul and long haul operations

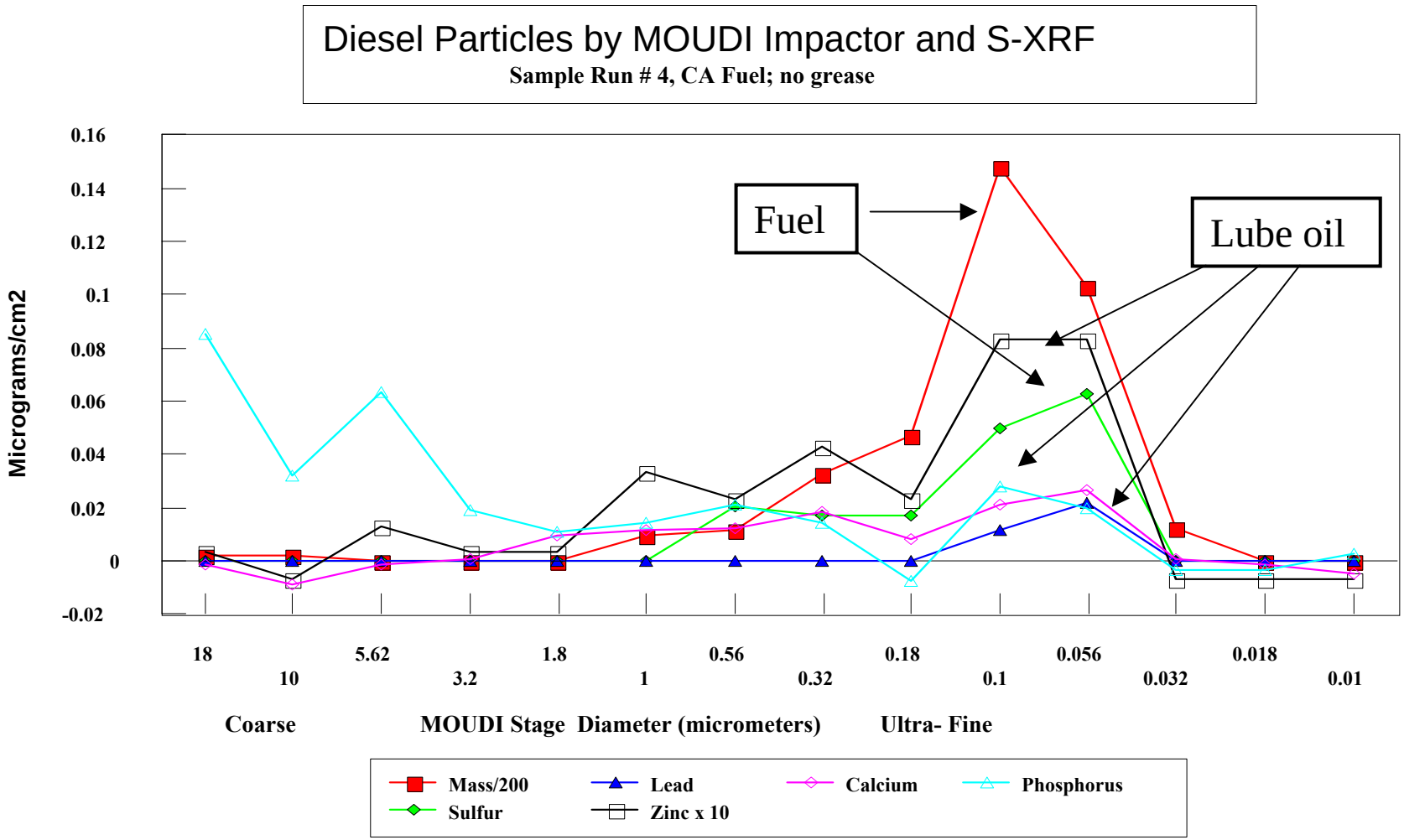
Diesel Particles by MOUDI Impactor and S-XRF

Sample Run # 4, CA Fuel; no grease



For micrograms/m3, times 8.7
DELTA Group, S-XRF, UC Davis

U. Minn. Dynamometer Diesel tests



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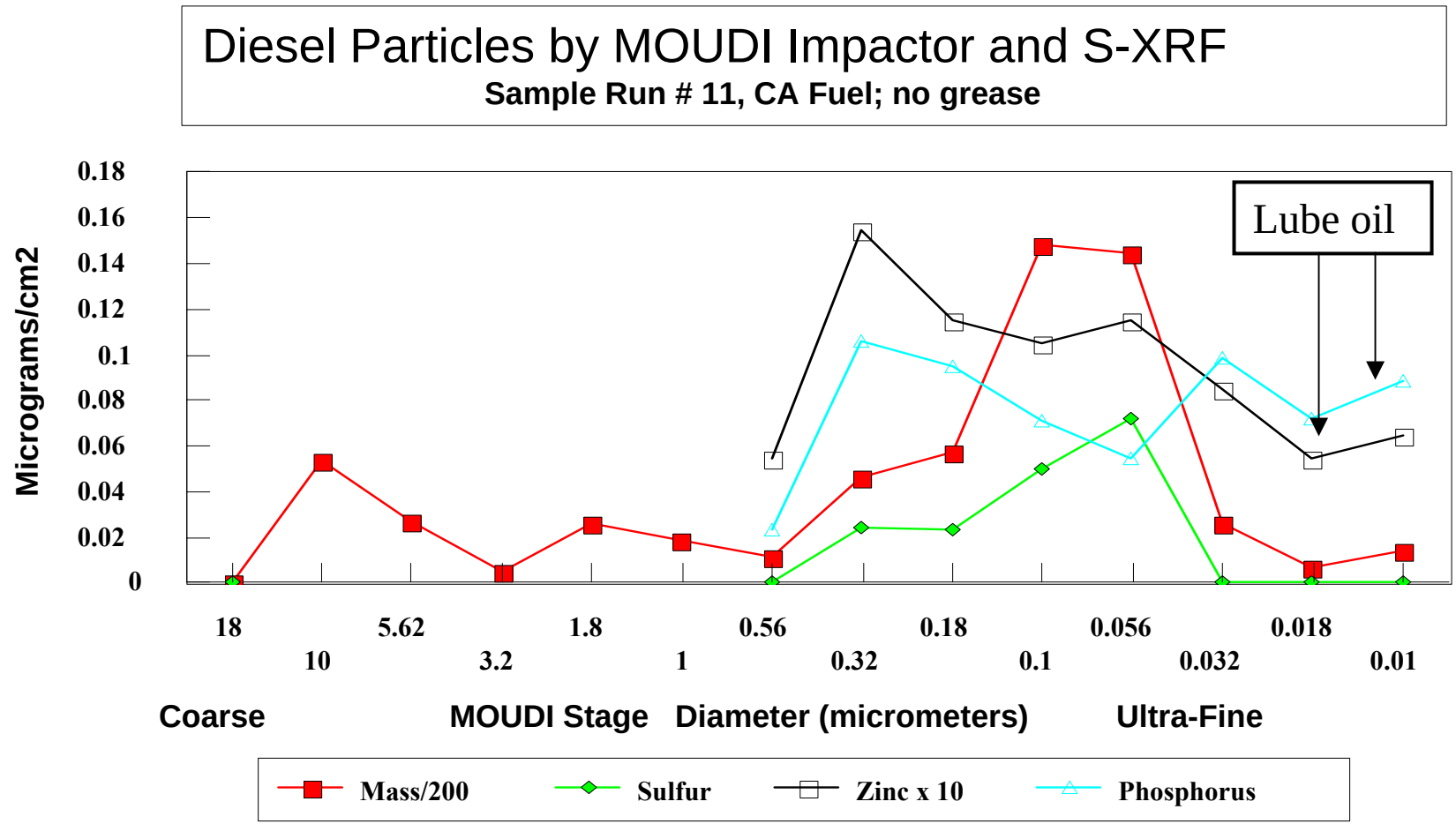
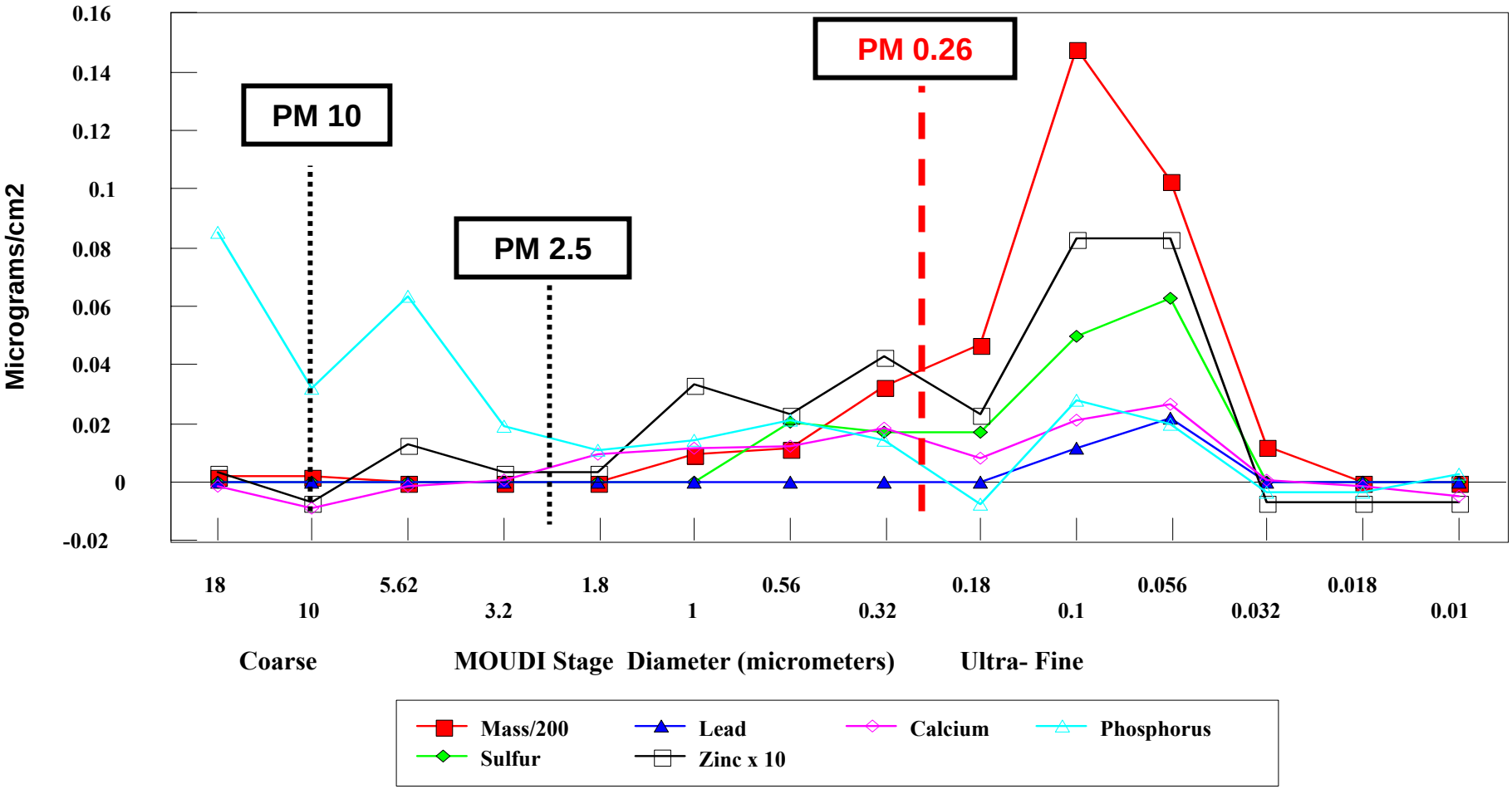
U. Minnesota Dynamometer Diesel Tests



For micrograms/m3, times 8.7
DELTA Group, S-XRF, UC Davis

Diesel Particles by MOUDI Impactor and S-XRF

Sample Run # 4, CA Fuel; no grease



For micrograms/m3, times 8.7
DELTA Group, S-XRF, UC Davis

Average Zn to mass, all DRI tests, 1800 ± 1300

Cars and all spark ignition (SI) engines

- A potentially clean technology
  - Low octane fuel no longer fixes NO
  - Low molecular weight fuel - less toxic organics
  - Tolerances make cylinder lubrication easier
- Post combustion clean up effective and cheap
  - Effective removal of CO and ozone precursors
- However, relaxed cylinder tolerances can exacerbate particle formation from burned lubricating oil

PM2.5 Aerosol Emission Factors, Heavy Duty and Light Duty Vehicle

Gertler et al, Health Effects Institute (2002)

Note: CA RFG vehicles 0.4 to 2 mg/km

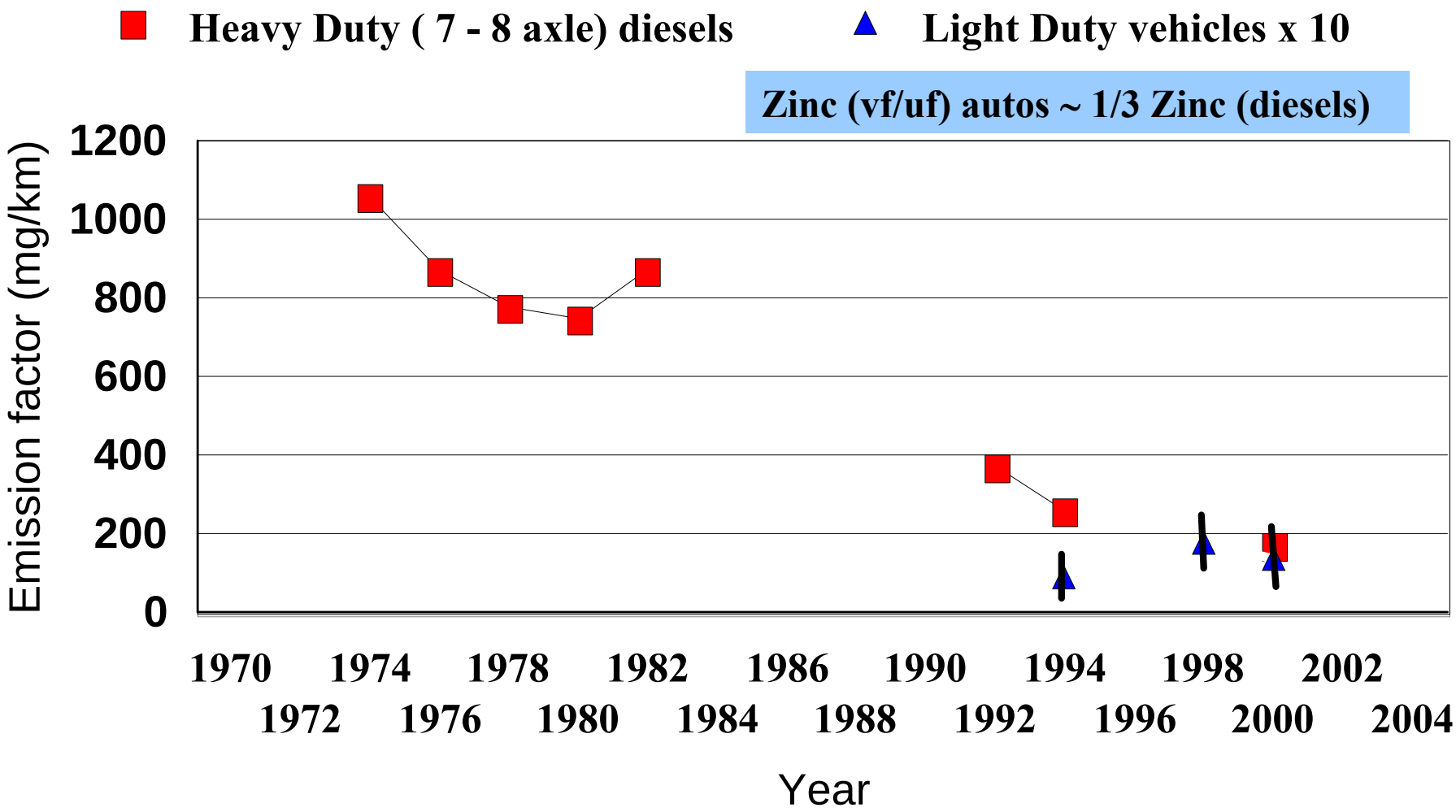
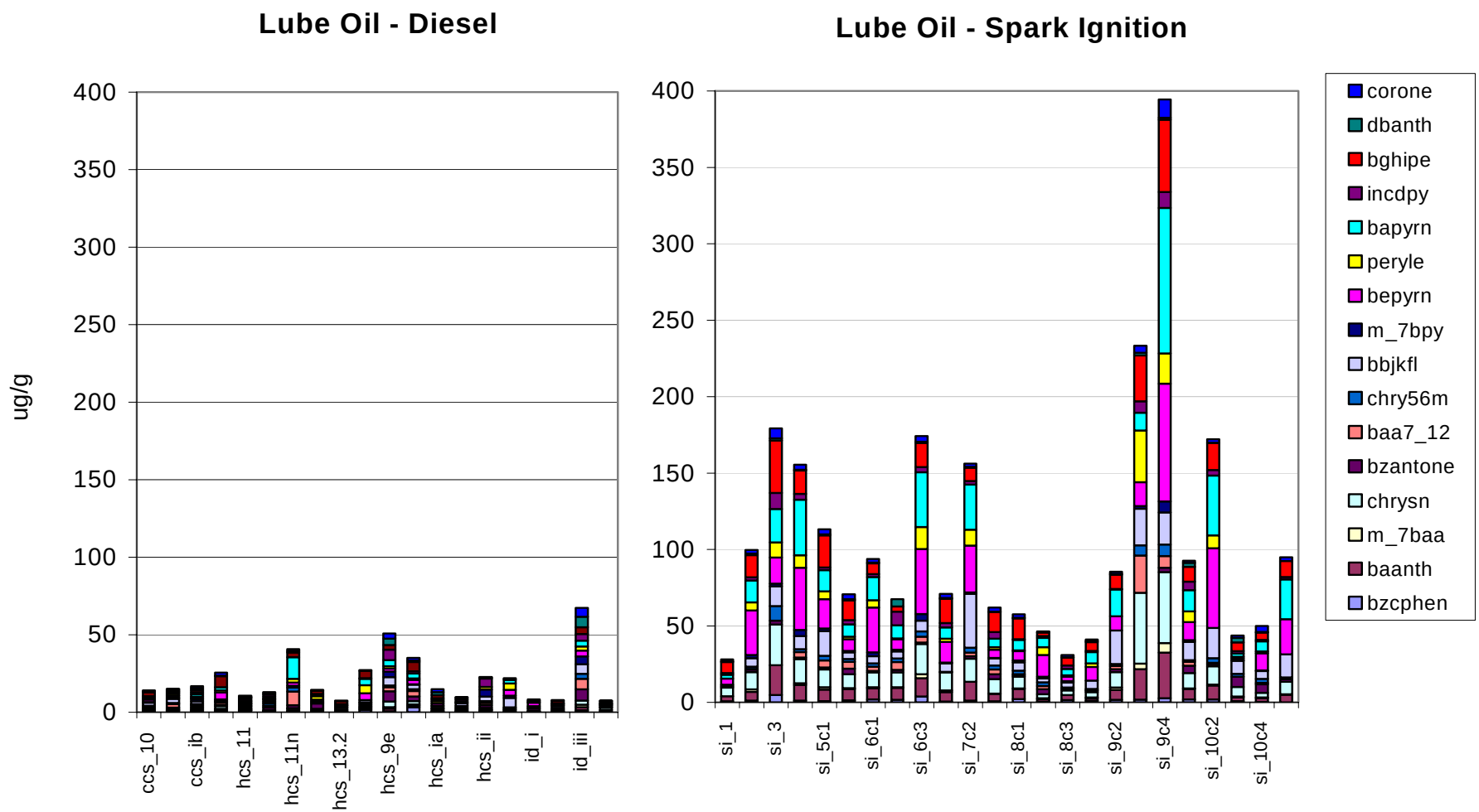


Table 1 Comparison to heavy duty and light duty PM_{10} and $PM_{2.5}$ emission rates form the Gertler at al 2002 Tuscarora Tunnel studies and other studies.

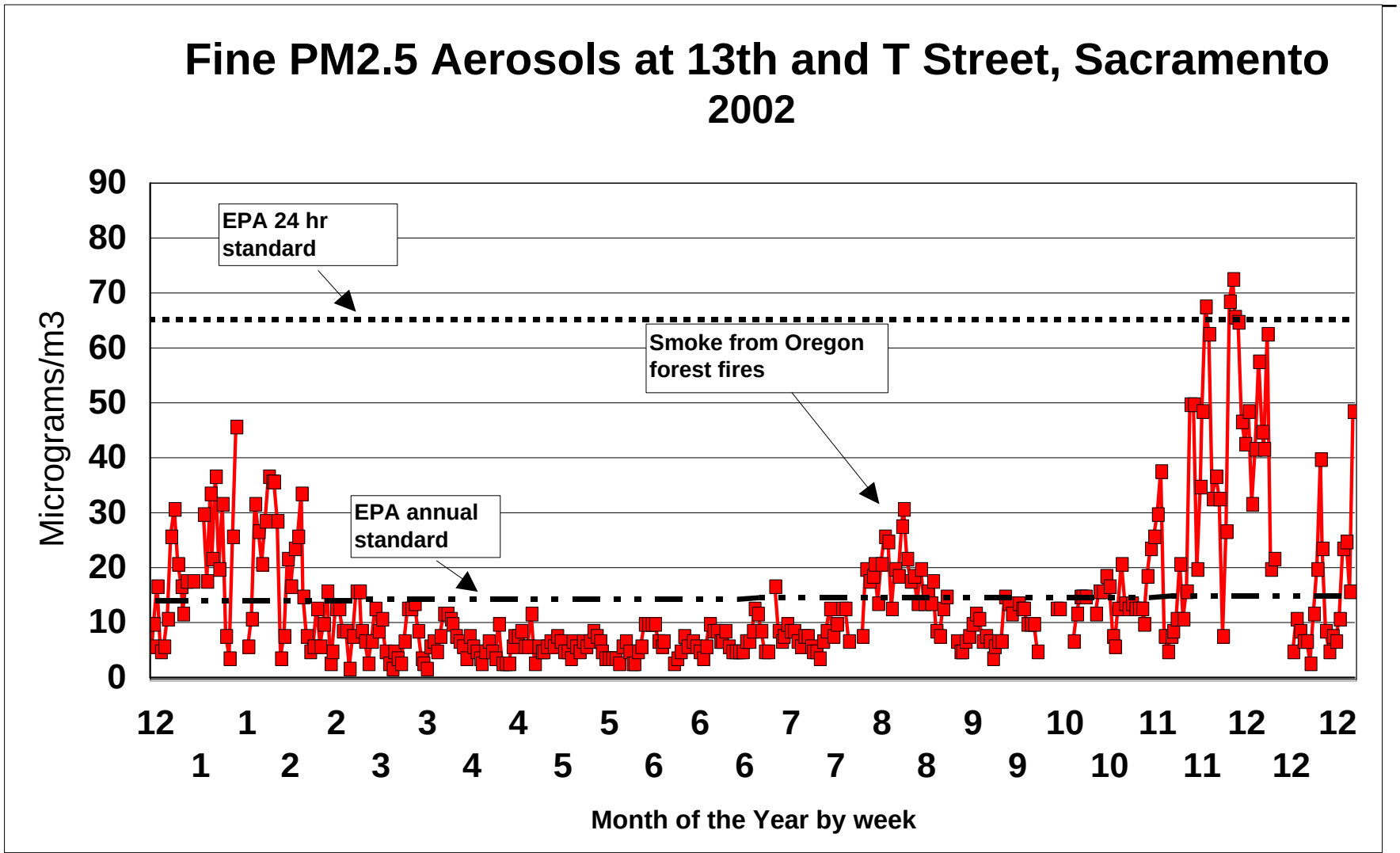
Parameter			Heavy duty (mg/km)	Light duty (mg/km)	Mixed (mg/km)
PM_{10} mass	Gertler 2002	Tuscarora	181 ± 13	10 ± 11	87 ± 54
$PM_{2.5}$ mass	Gertler 2002	Tuscarora	135 ± 18	14 ± 13	62 ± 42
PM_{10} mass	Gillies 2001	Sepulveda	na	Na	69 ± 30
$PM_{2.5}$ mass	Gillies 2001	Sepulveda	na	Na	53 ± 27
$PM_{2.5}$ mass	Norbeck 1998	In-use (med)		18 ± 9	
$PM_{2.5}$ mass	Norbeck 1998	In-use (high)		185 ± 50	
PM_{10} mass	Sagebiel 1997	High CO, HC		346 smoke	
PM_{10} mass	Sagebiel 1997	High CO, HC		32 no smoke	

From these results, we see that diesel is about 18 times worse than light duty vehicles for PM_{10} emissions and 10 times worse than light duty vehicles for $PM_{2.5}$ emissions, and that the worst case smoking car is about the same as the average diesel. Incidentally, these emission values are sharply lower than occurred only a decade ago.

DOE Gasoline/Diesel PM Split Study
Particle-Phase PAH in Lubrication Oil

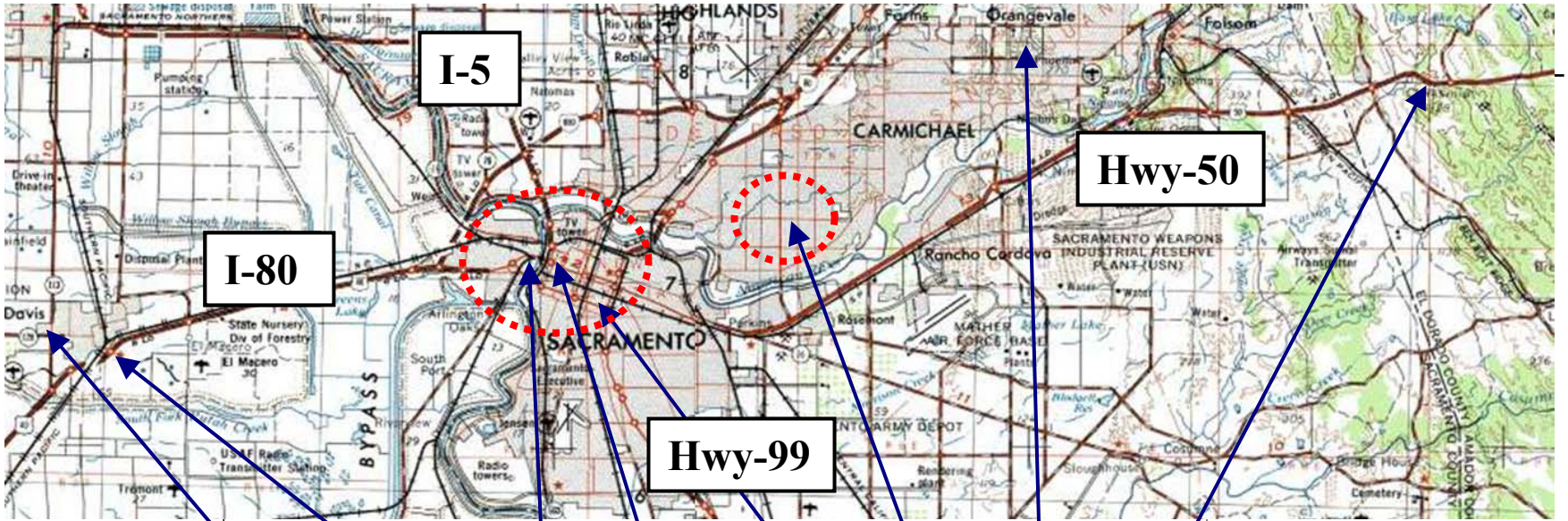


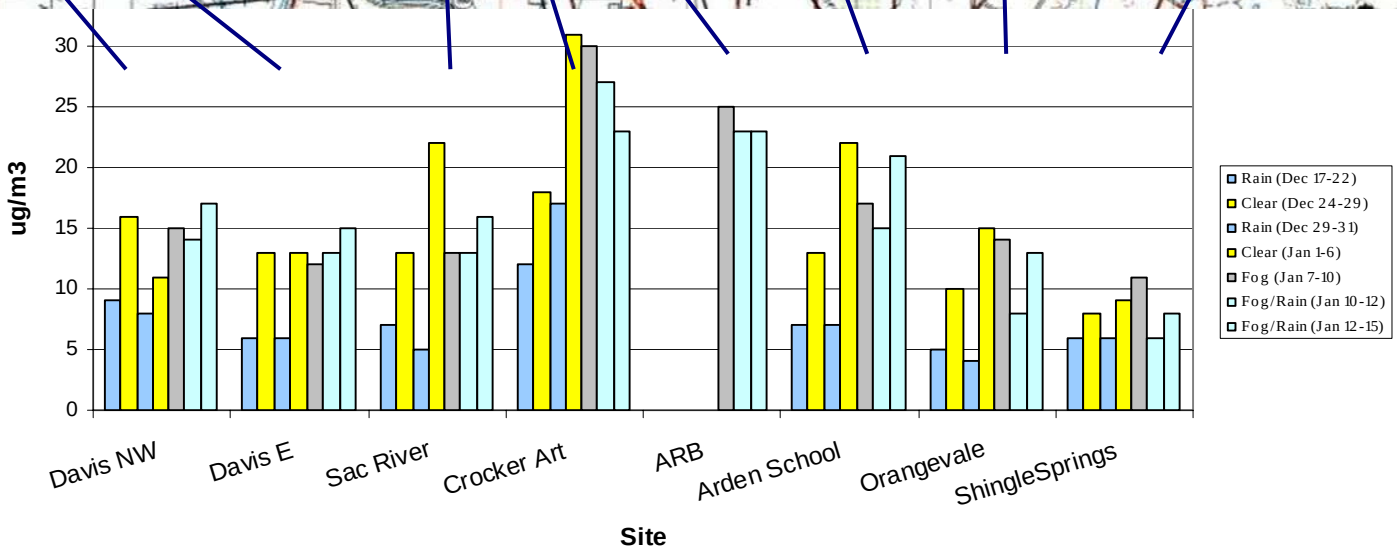
Sacramento – a highway nexus, (I-5, I-80, Hwy 50, Hwy 99) and close to violations of $PM_{2.5}$ standards



Lung Assoc. Sacramento Transect Study Site Map and $PM_{2.5}$ aggregated data

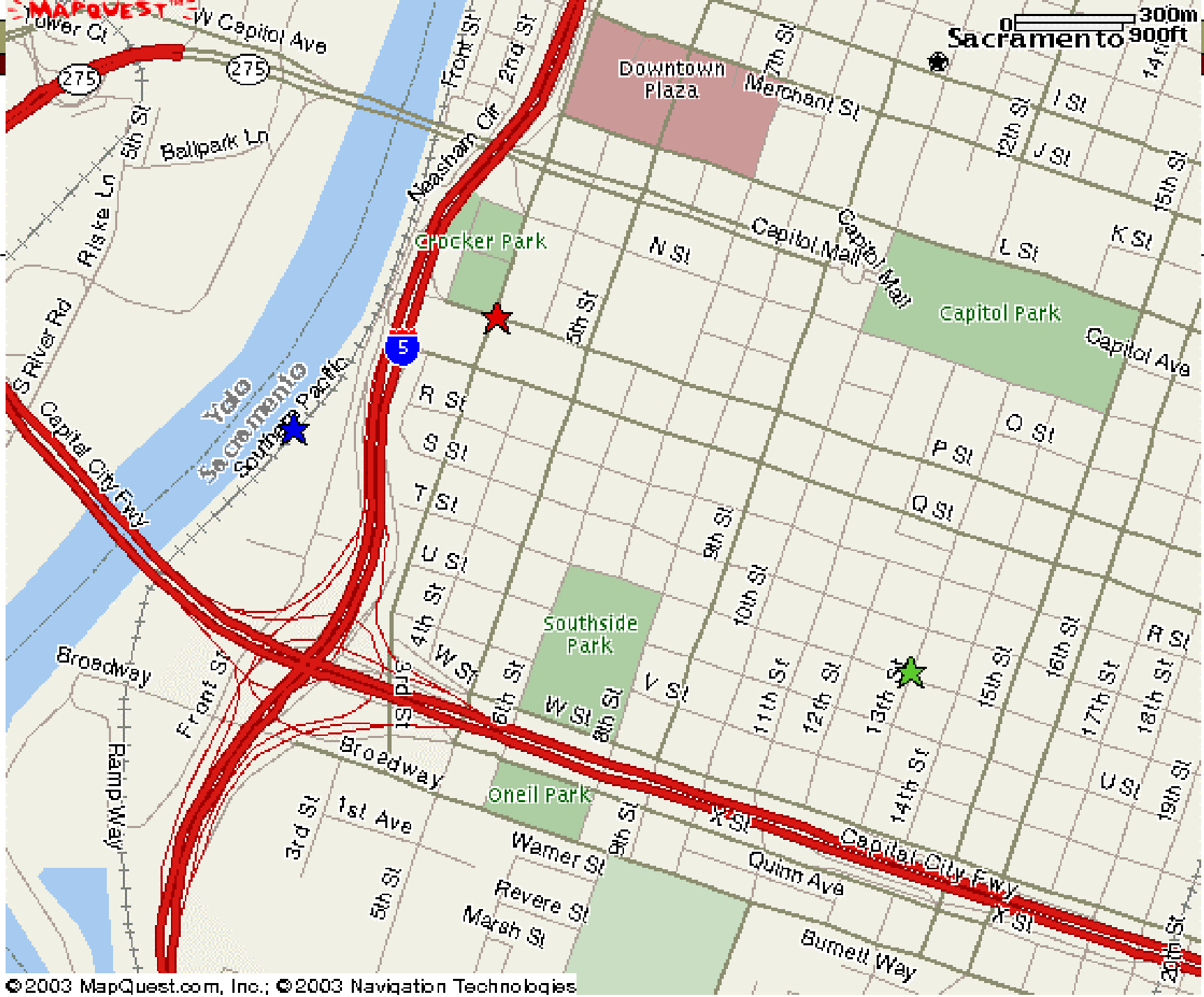
#1, #3 - light blue = rain, yellow = “clear”, rest = fogs, wet and dry



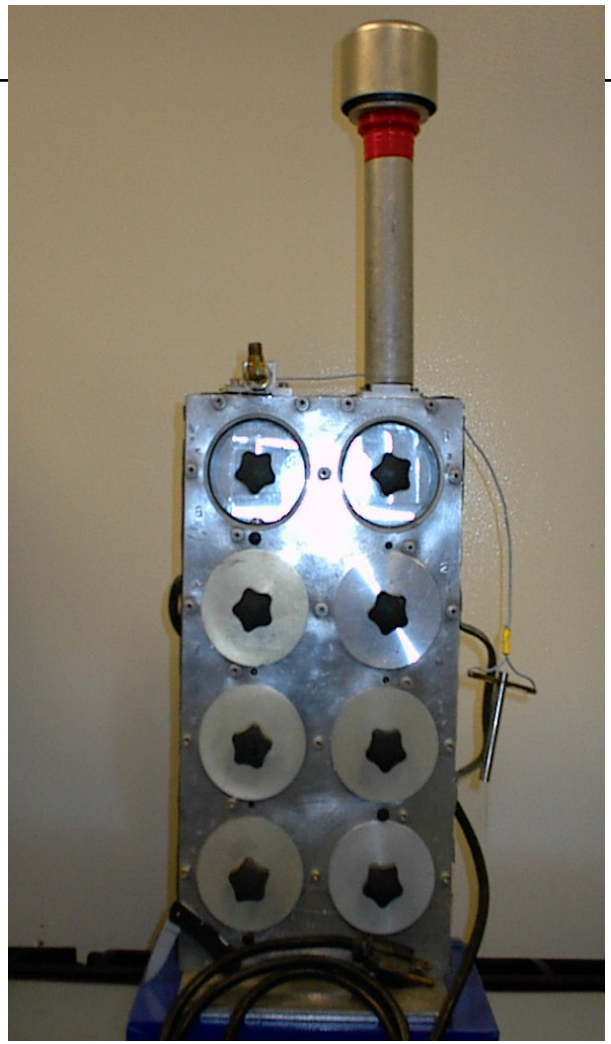


Interstate 5 in Sacramento

- Impact of I-5 on Downtown Sacramento
  - 10,500 light duty, 1125 heavy duty (> 5 axel) vehicles/hr,
  - 10 traffic lanes, nearest 100 m to Crocker Art Museum site
  - Sound wall; some trees but not a barrier
  - Prevailing wind in daytime from southwest, across I-80; stagnation low winds from southeast
  - Cut section freeway; complex terrain prevents direct line source modeling; use very fine diesel tracers



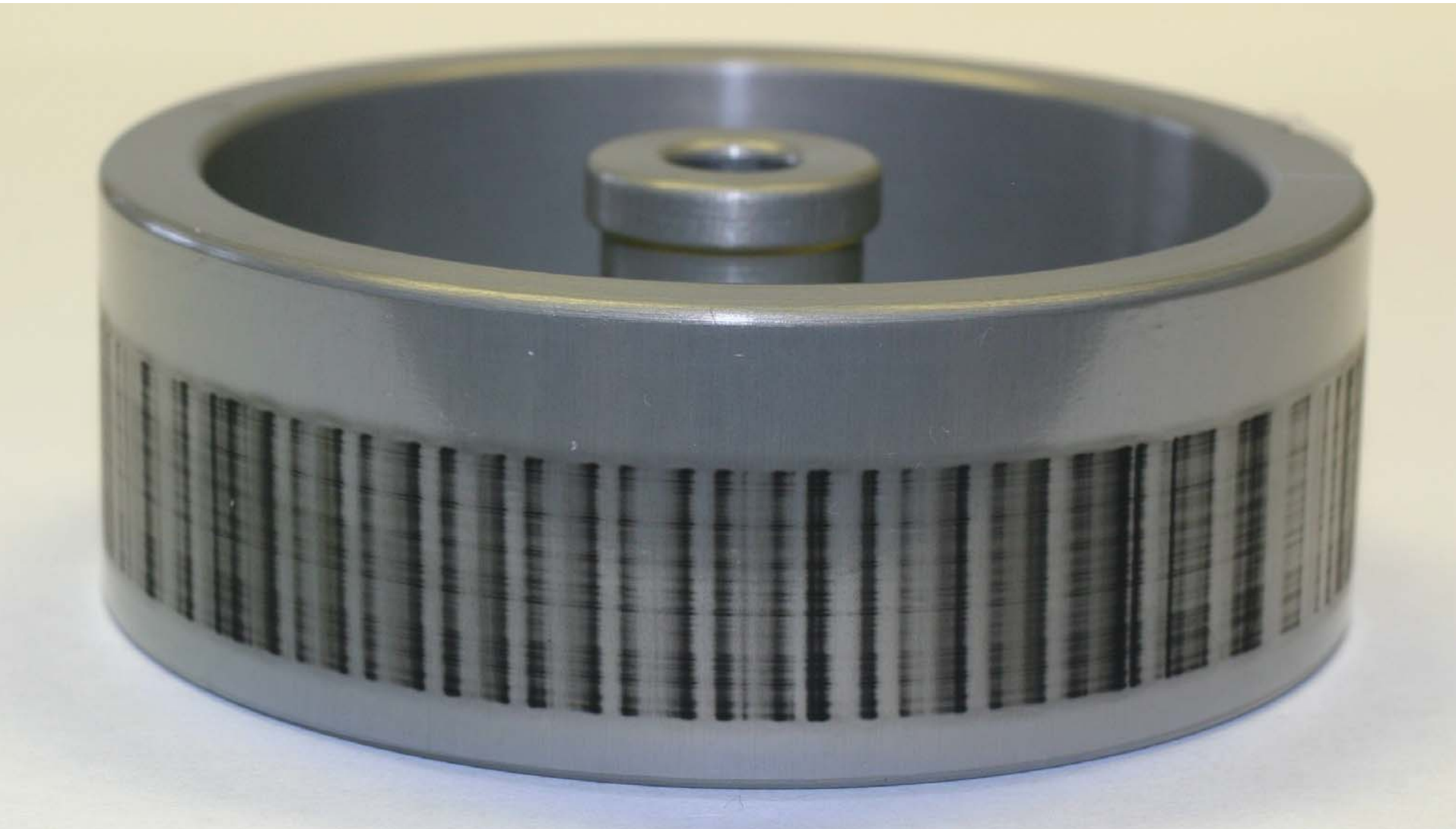
DELTA Group slotted 8 DRUM Impactor

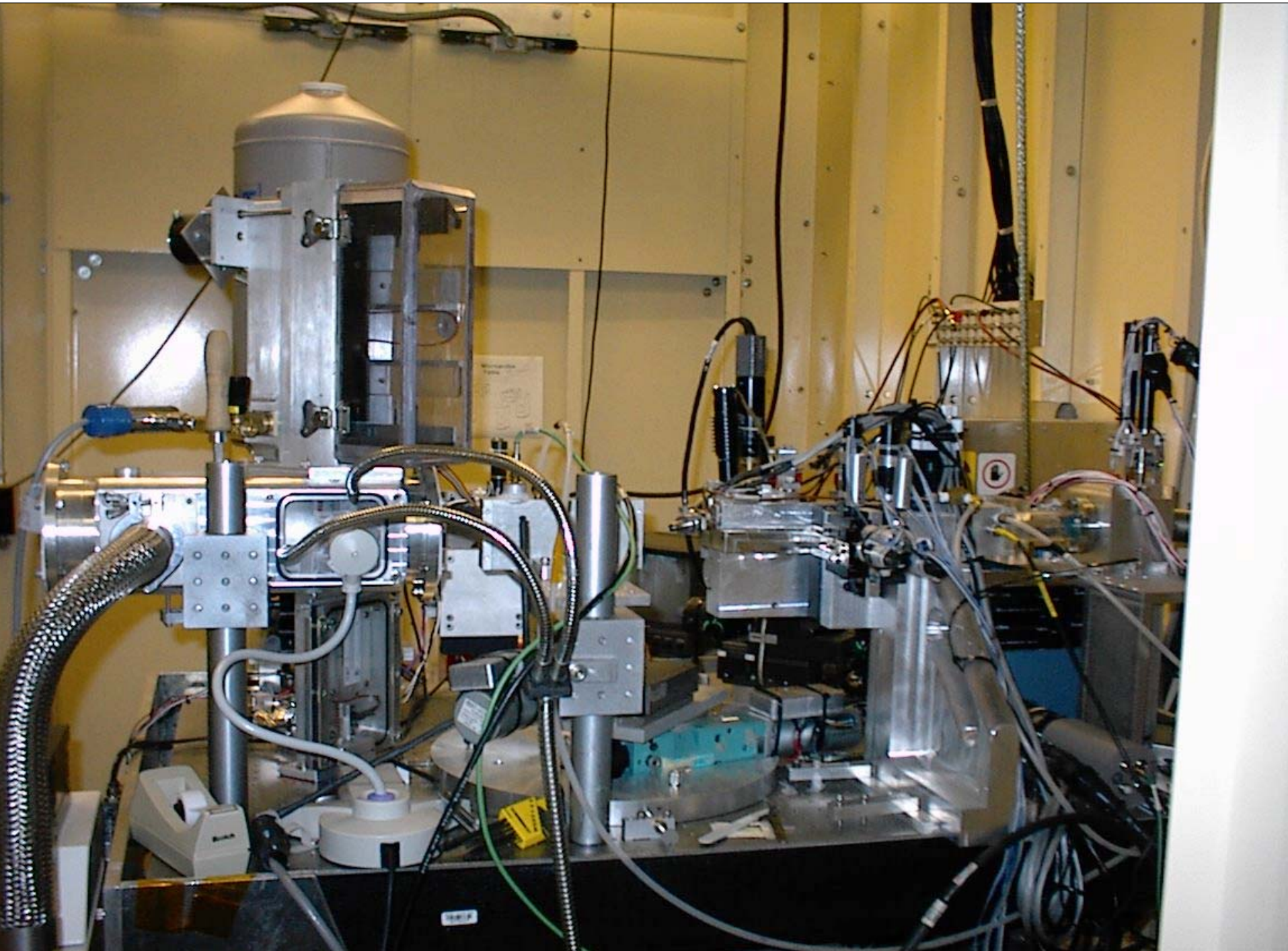


- **8 size ranges:**
  - **Inlet (~ 12) to 5.0 µm**
  - **5.0 to 2.5 µm**
  - **2.5 to 1.15 µm**
  - **1.15 to 0.75 µm**
  - **0.75 to 0.56 µm**
  - **0.56 to 0.34 µm**
  - **0.34 to 0.26 µm**
  - **0.26 to 0.09 µm**
- **10.4 l/min, critical orifice control, ¼ hp pump**
- **6.5 x 168 mm Mylar strips**
- **For 42 day run, 4 mm/day,**

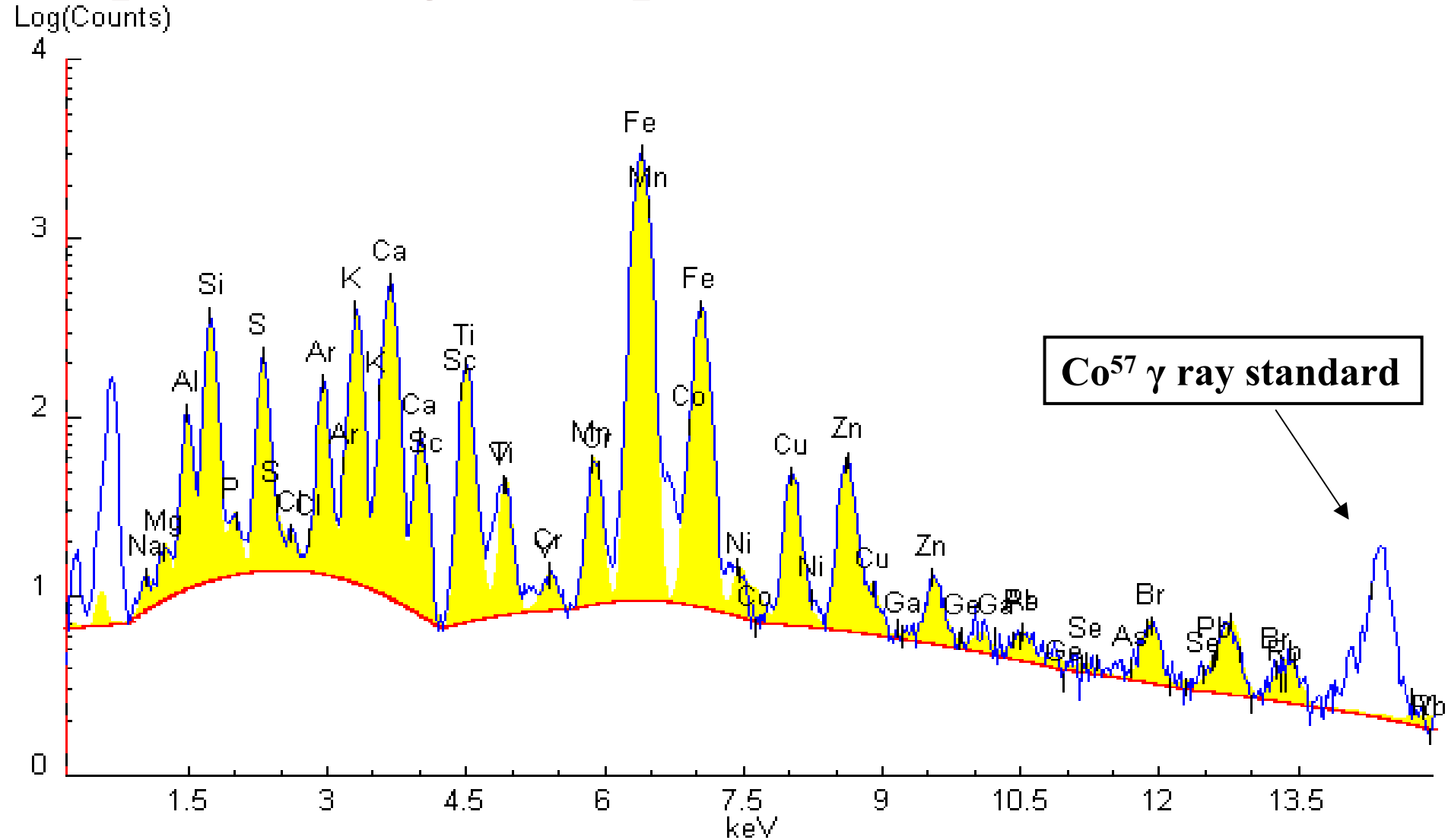
  time resolution = 3 hr.
- **Field portable**
  - **10 kg, 43 × 22 × 13 cm**

Very fine ($0.26 > D_p > 0.09$ µm) DRUM sample, 3 weeks, South Lake Tahoe; 1cm high, true color





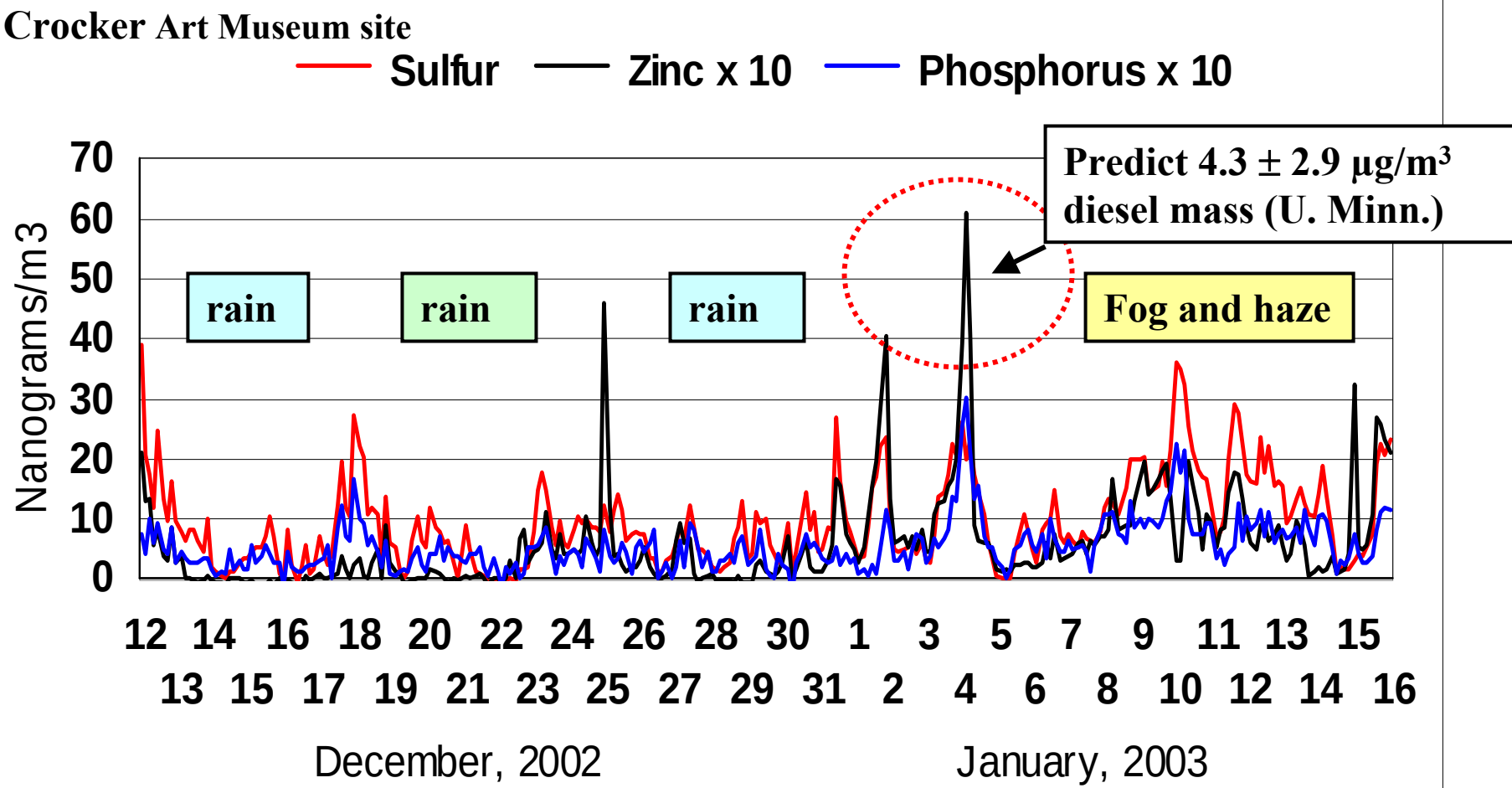
UC Davis DELTA Group S-XRF x-ray spectrum, light sample; no blank subtraction

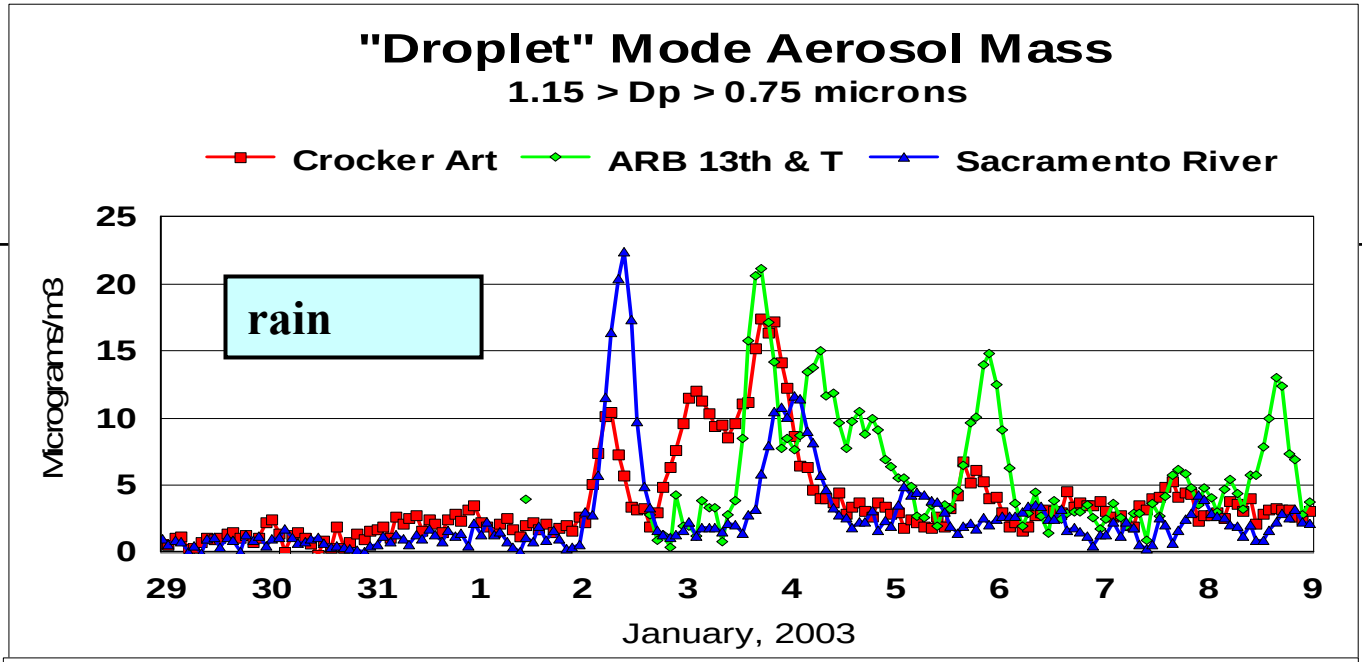


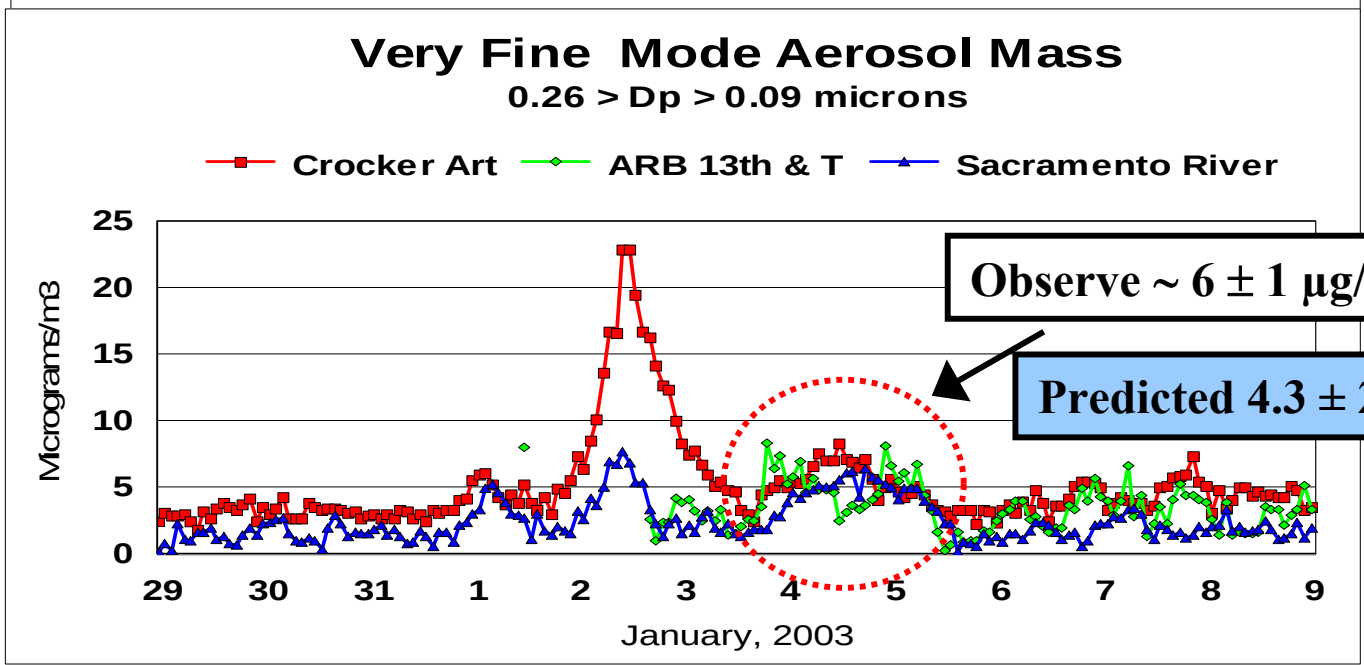
ALASET HETF Sacramento I-5 Transect Study

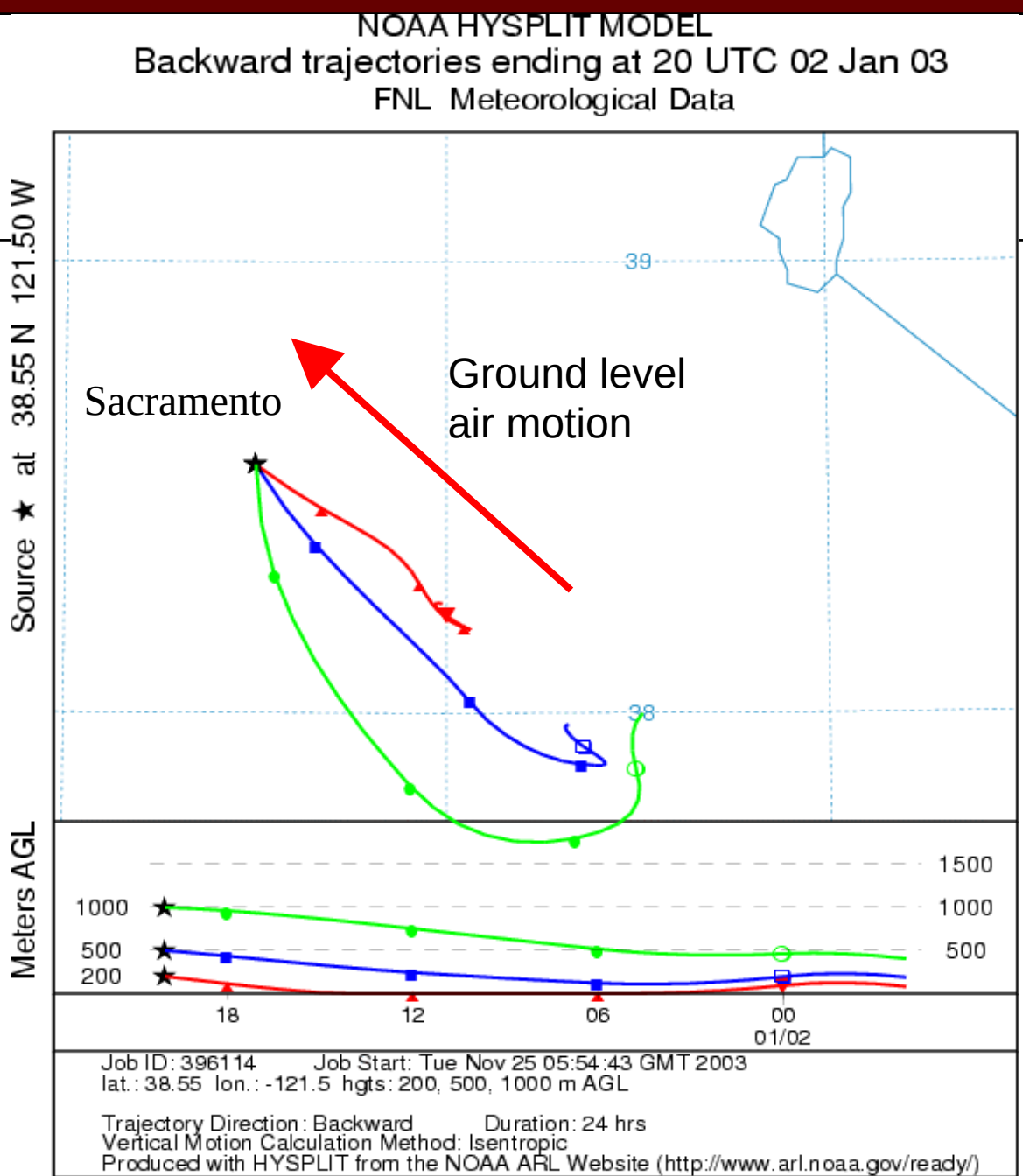
DELTA DRUM very fine particles (0.26 > Dp > 0.09microns) , S-XRF analysis

Possible tracers of diesel exhaust

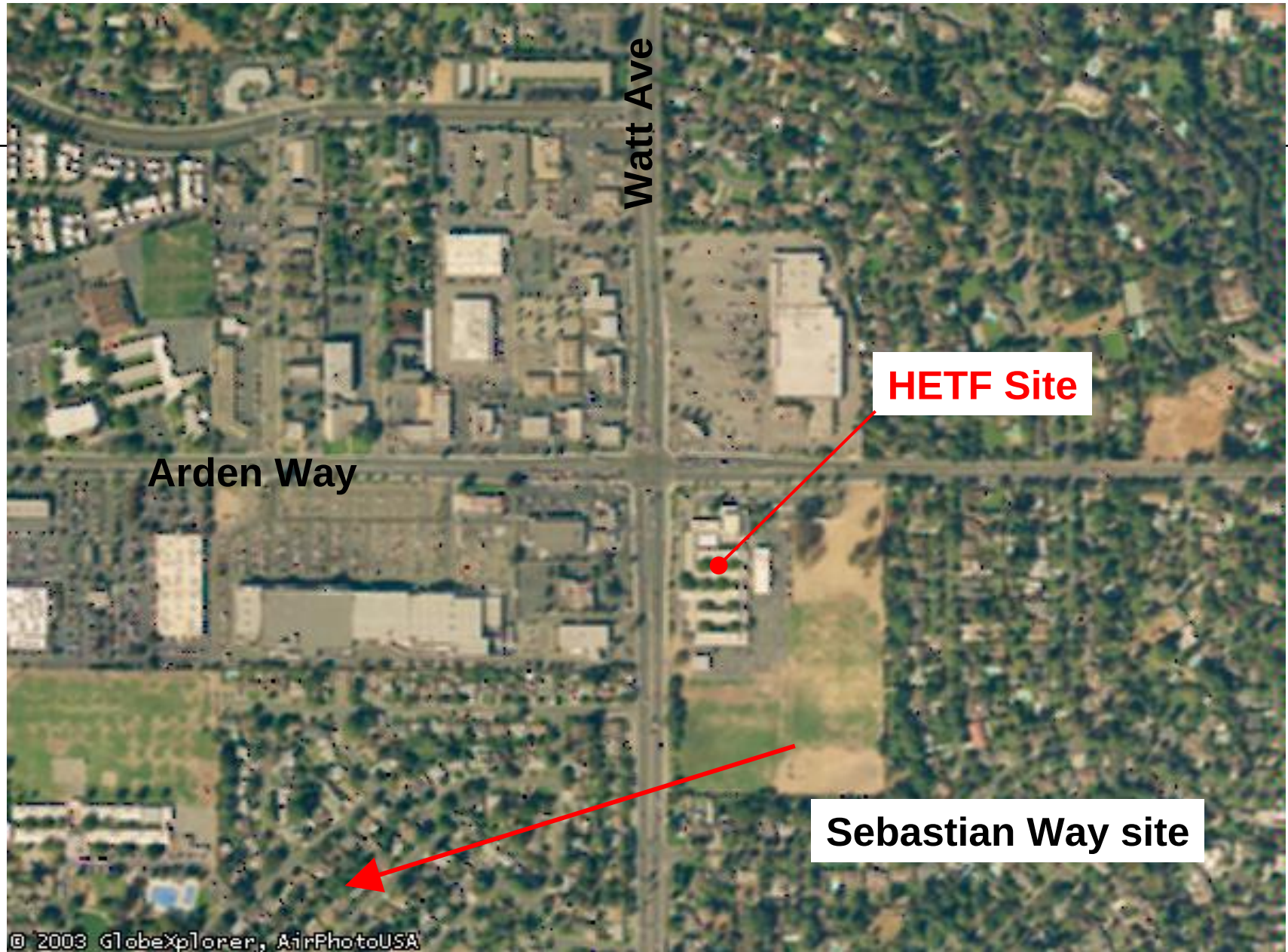


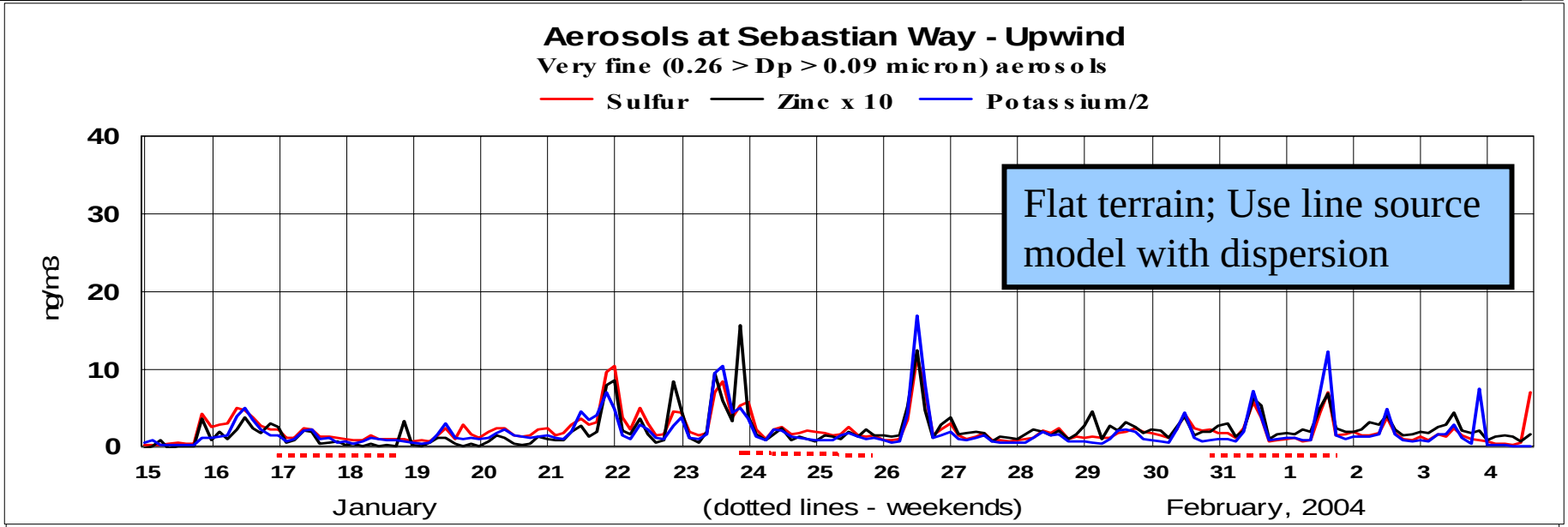

"Droplet" Mode Aerosol Mass
1.15 > Dp > 0.75 microns
Crocker Art
ARB 13th & T
Sacramento River
Micrograms/m3
25
20
15
10
5
0
rain
29
30
31
1
2
3
4
5
6
7
8
9
January, 2003

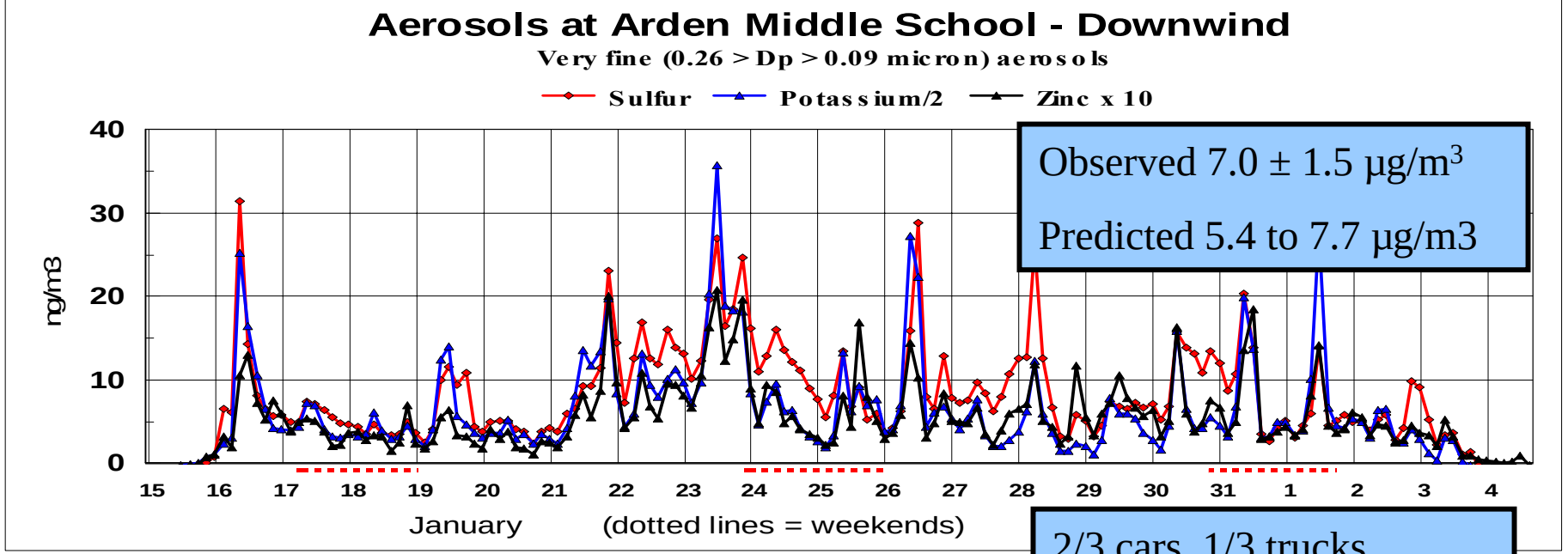

Very Fine Mode Aerosol Mass
0.26 > Dp > 0.09 microns
Crocker Art
ARB 13th & T
Sacramento River
Micrograms/m3
25
20
15
10
5
0
Observe ~ 6 ± 1 µg/m3 mass
Predicted 4.3 ± 2.9 µg/m3
29
30
31
1
2
3
4
5
6
7
8
9
January, 2003


NOAA HYSPLIT MODEL
Backward trajectories ending at 20 UTC 02 Jan 03
FNL Meteorological Data
Source ★ at 38.55 N 121.50 W
Sacramento
Ground level
air motion
39
38
Meters AGL
1500
1000
500
1000
500
200
18
12
06
00
01/02
Job ID: 396114 Job Start: Tue Nov 25 05:54:43 GMT 2003
lat.: 38.55 lon.: -121.5 hgts: 200, 500, 1000 m AGL
Trajectory Direction: Backward Duration: 24 hrs
Vertical Motion Calculation Method: Isentropic
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/ready/)

Map of the Arden Middle School site



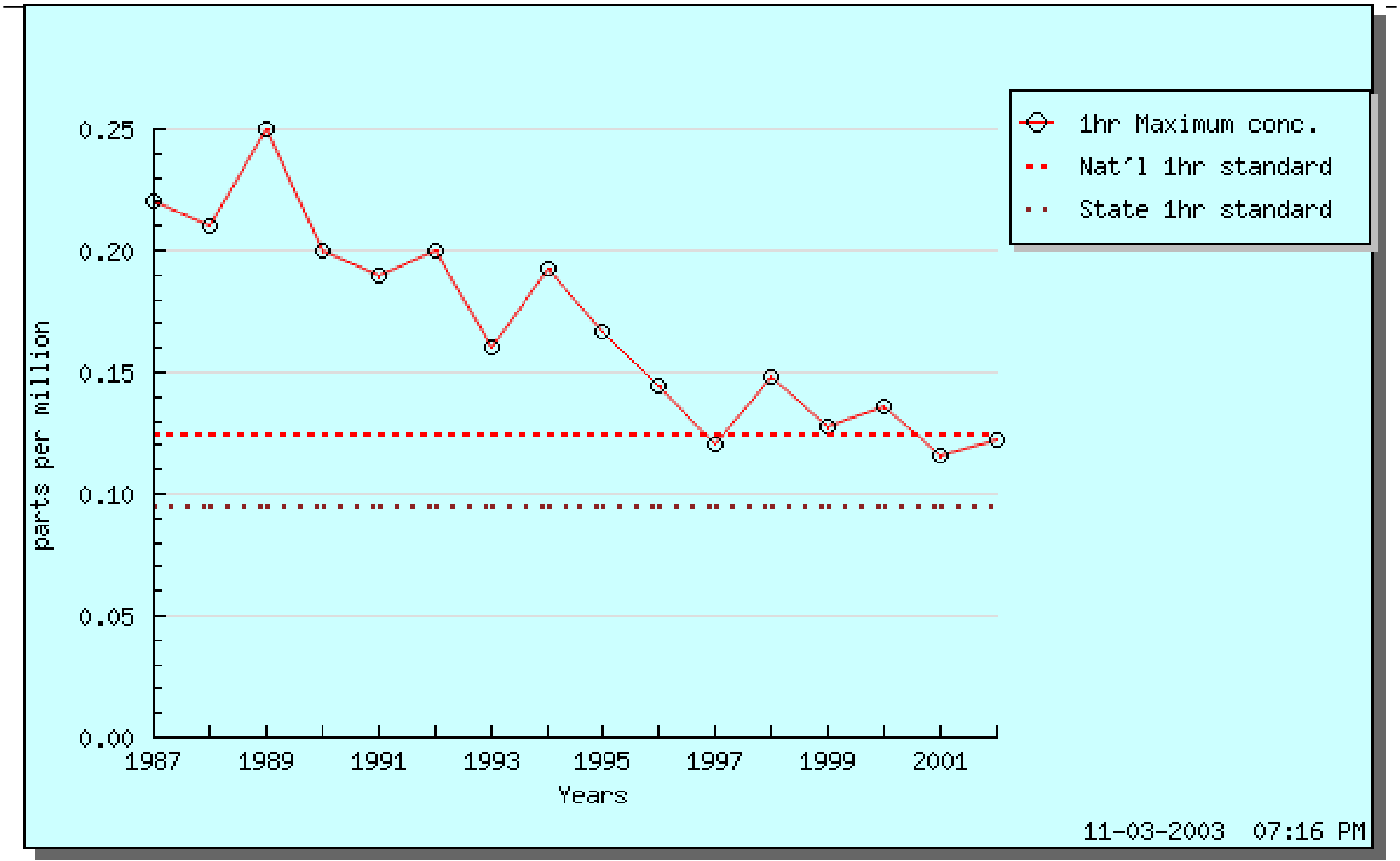

Aerosols at Sebastian Way - Upwind
Very fine (0.26 > Dp > 0.09 micron) aerosols
Sulfur
Zinc x 10
Potassium/2
ng/m3
40
30
20
10
0
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4
January
(dotted lines - weekends)
February, 2004
Flat terrain; Use line source model with dispersion


Aerosols at Arden Middle School - Downwind
Very fine (0.26 > Dp > 0.09 micron) aerosols
Sulfur
Potassium/2
Zinc x 10
ng/m3
40
30
20
10
0
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4
January
(dotted lines = weekends)
Observed 7.0 ± 1.5 µg/m3
Predicted 5.4 to 7.7 µg/m3
2/3 cars, 1/3 trucks

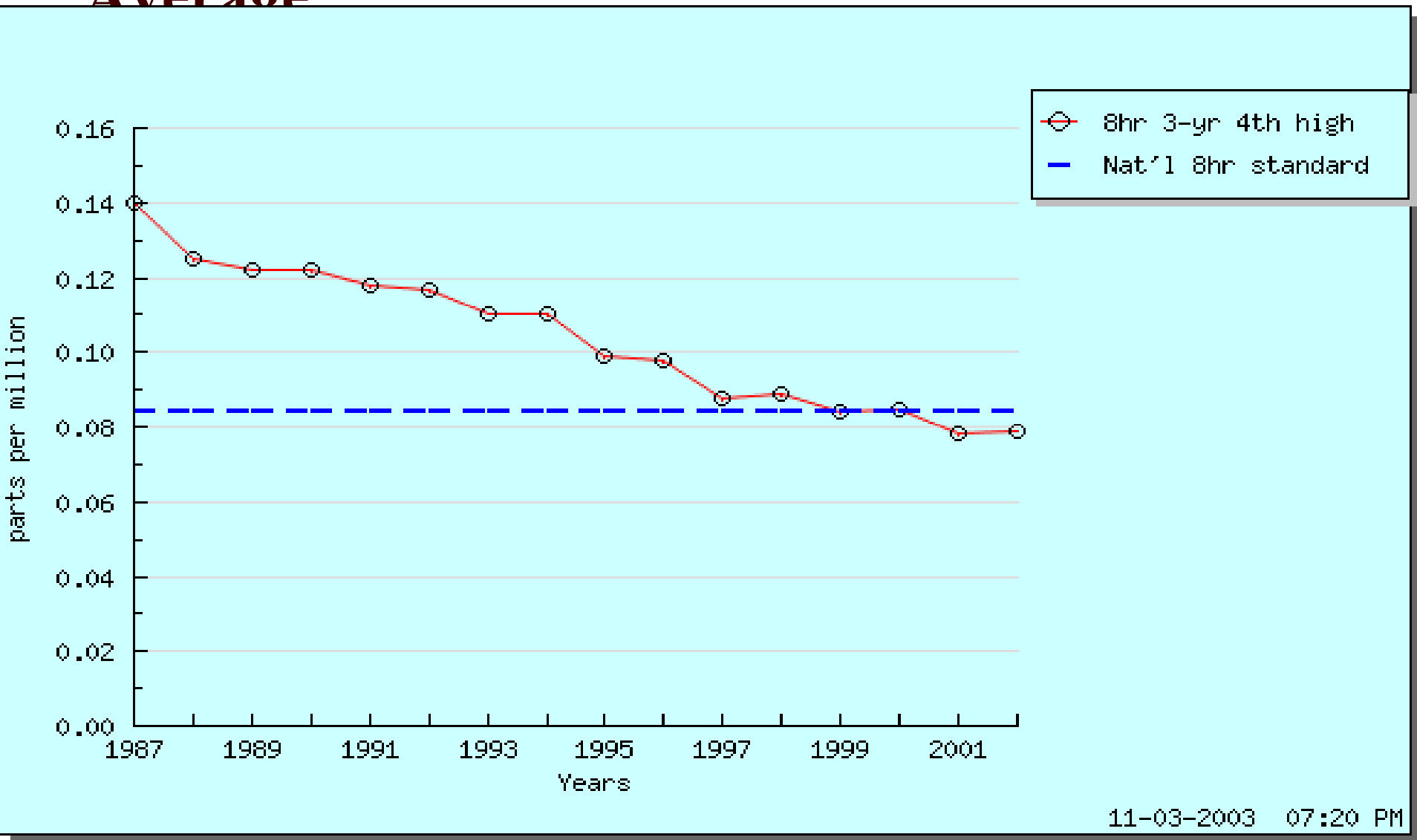
What about other Central valley sites?
Fresno, the new “ground zero” for the smog wars

- EPA ARB First Street “Supersite yields additional data
  - Light local traffic in a residential/small commercial area
  - About 1 km east of Highway 41 (117K cars, 5 K trucks),
  - 5 km north east of Highway 99 (60K cars, 15 K trucks trucks)
- But first, a word about ozone …….

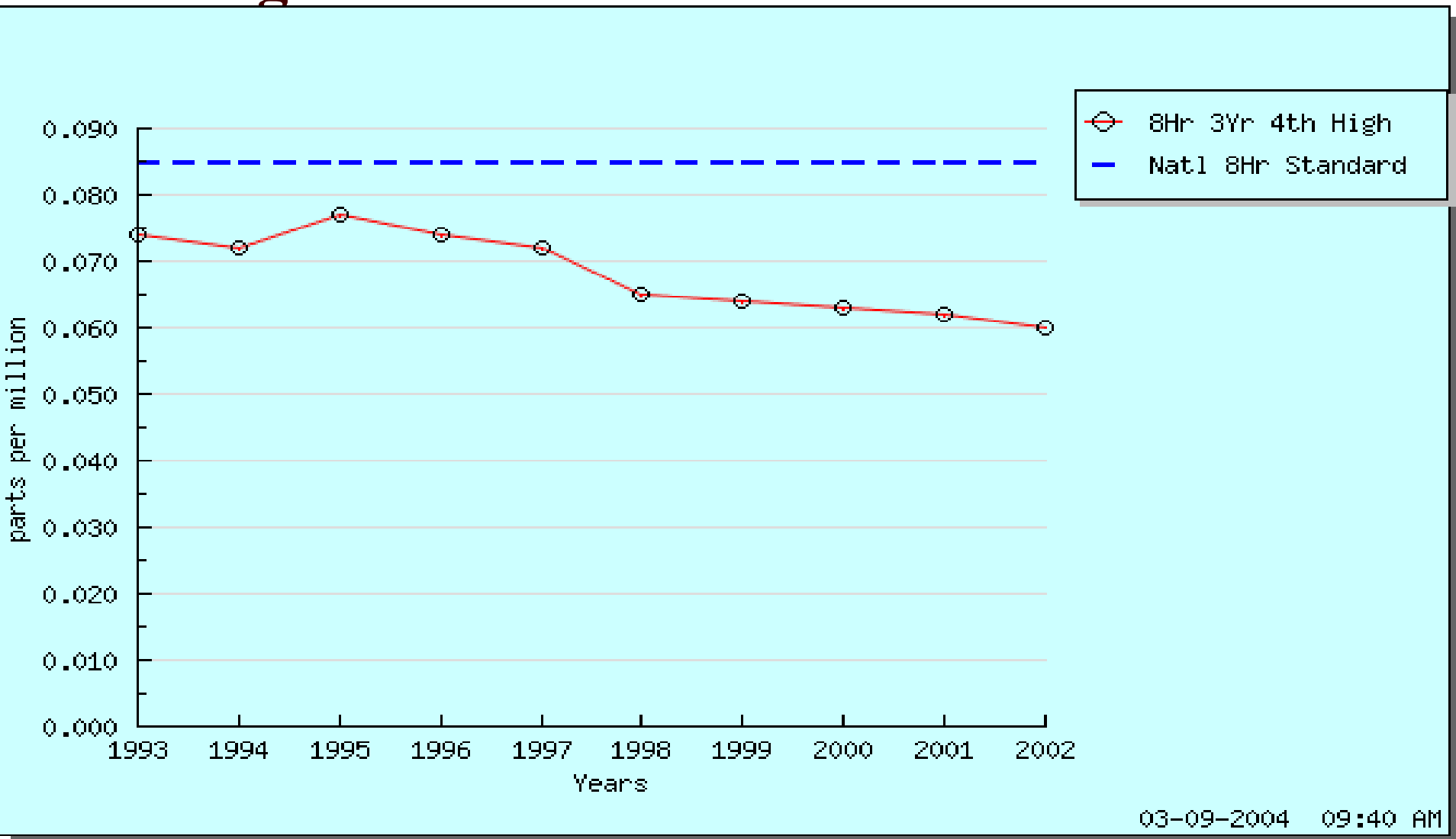
Great ozone reductions in Los Angeles



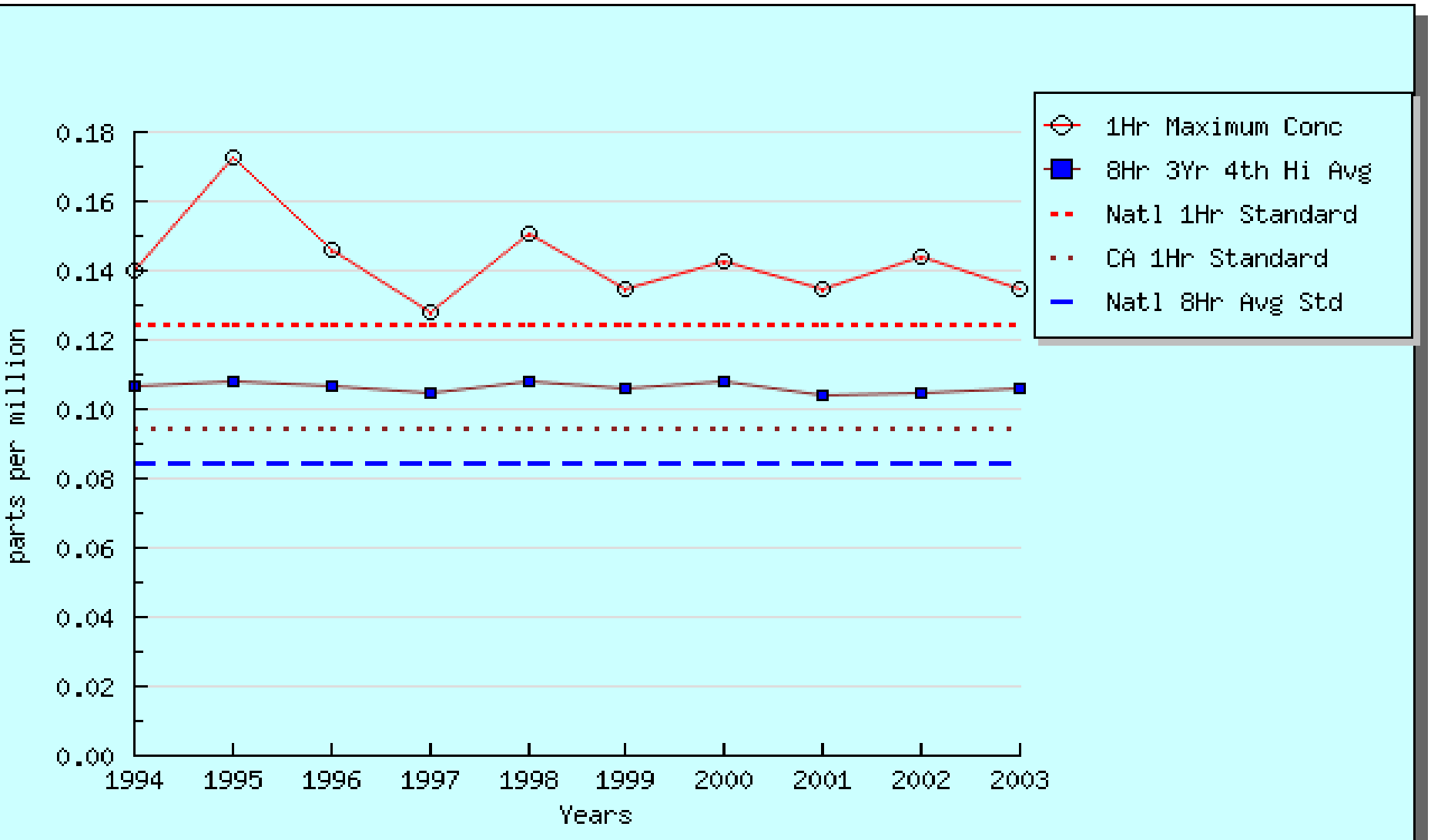
Los Angeles Ozone 8 hr 4th Highest 3 yr Average



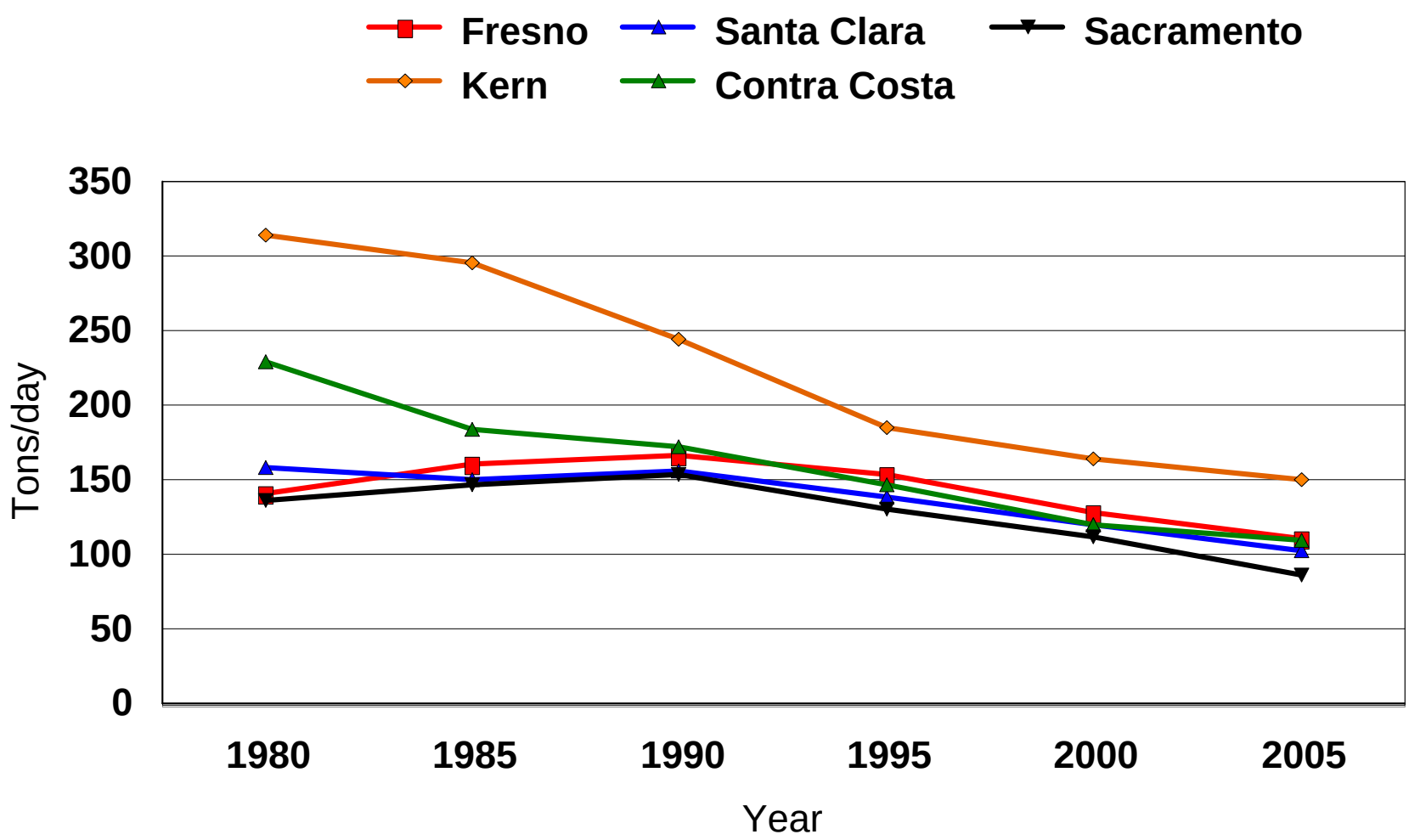
Alameda County Ozone 8 hr 4th Highest 3 yr Average



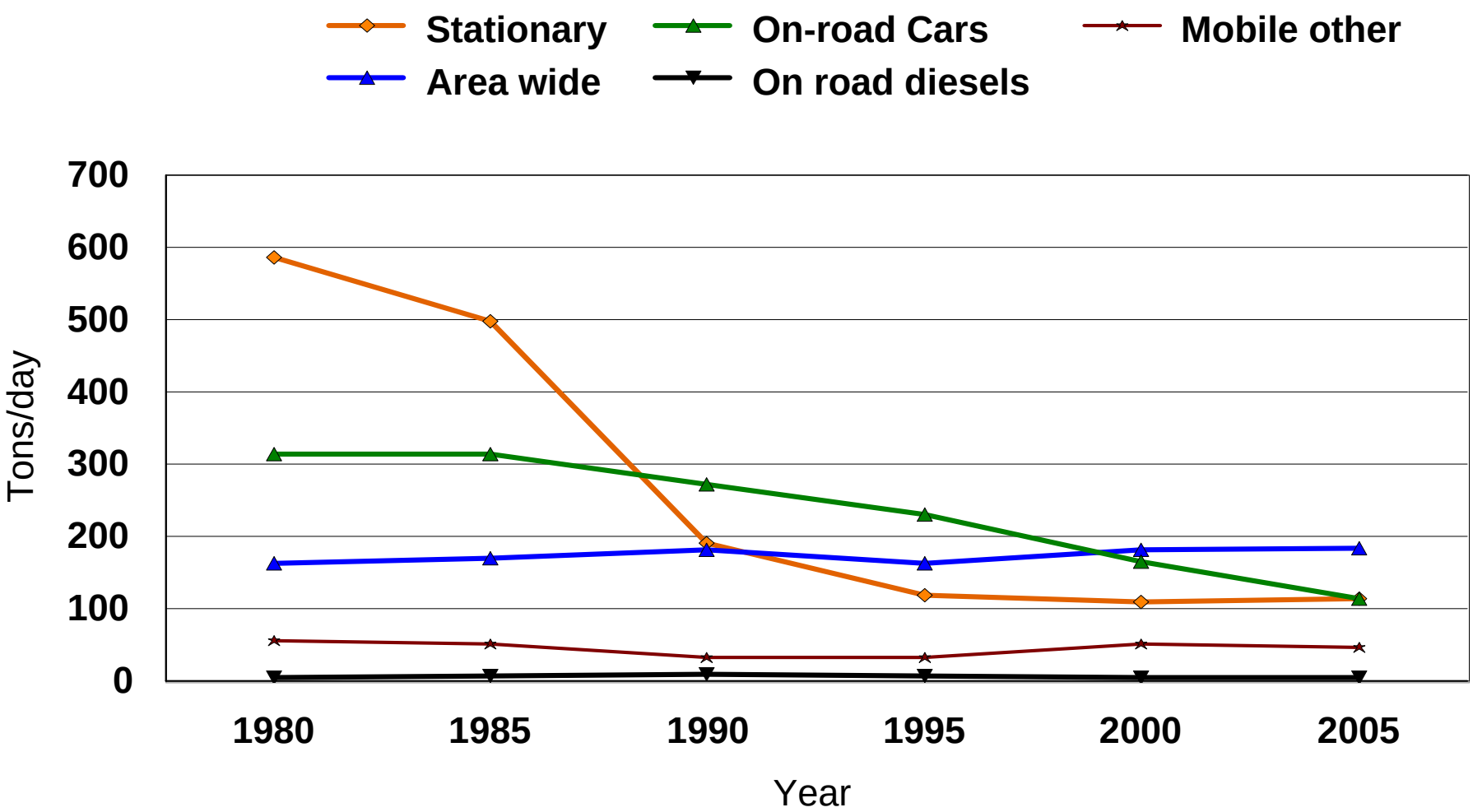
Little change in zone in the Central Valley



NOx Emissions by County



ROG Emission Trends in the San Joaquin Valley



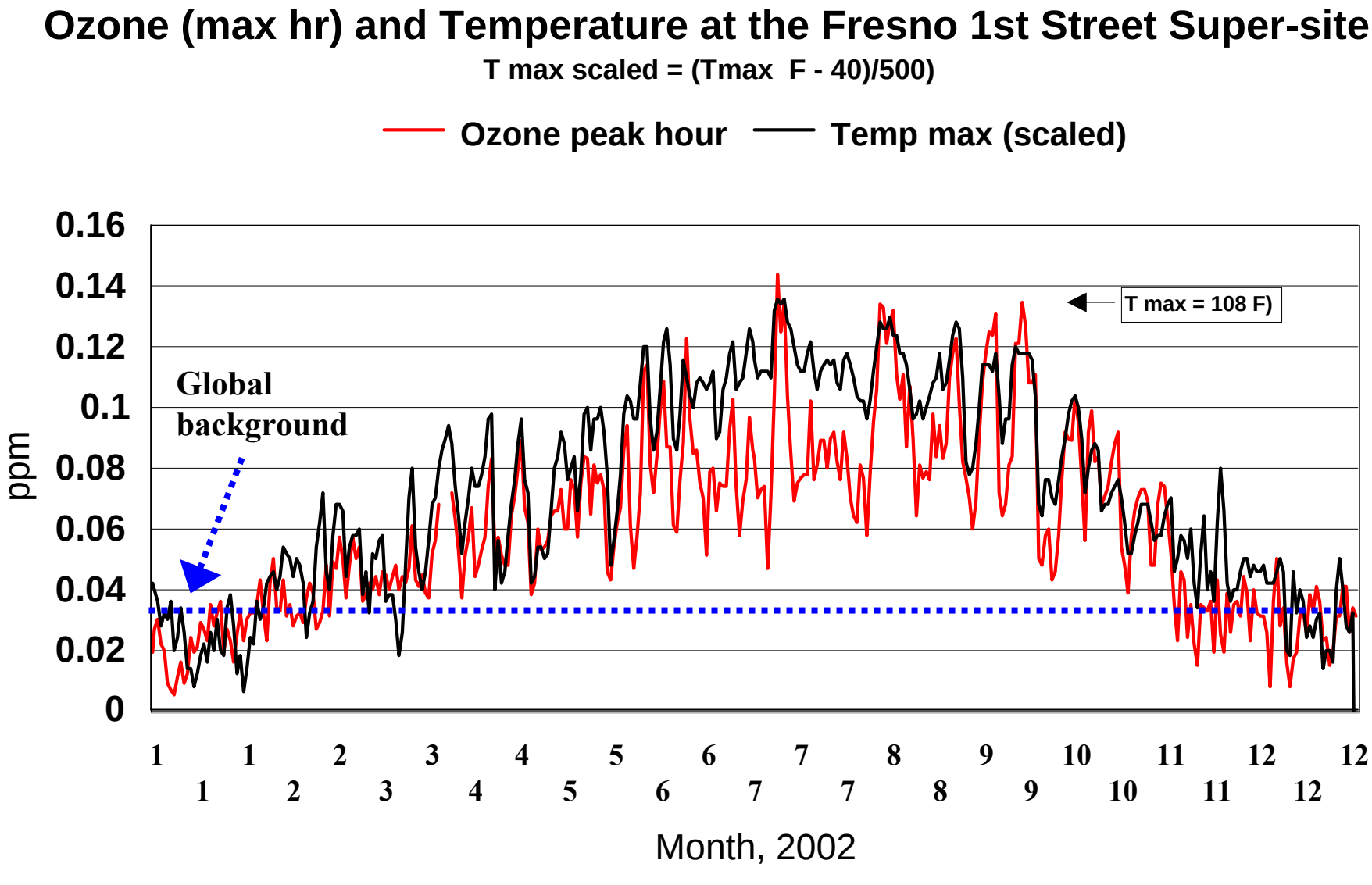
Los Angeles	1 hr ozone		0.50	50%	
	8 hr ozone		**0.58**	**42%**	
	ROG		0.45	55%	
	NO_x		0.52	48%	
		Avg ROG/NOx	**0.51**	**51%**	
		Yield	**(0.42/0.51)**		**82 %**
Bay Area	1 hr ozone		0.85	15%	
(Fremont)	**8 hr ozone**		**0.77**	**23%**	
	ROG		0.63	37%	
	NO_x		0.50	50%	
		Avg ROG/NOx	**0.44**	**44%**	
		Yield	**(0.23/0.44)**		**52 %**
San Joaquin Valley	1 hr ozone		0.87	13%	
(Fresno)	**8 hr ozone**		**0.98**	**2%**	
	ROG		0.45	55%	
	NO_x		0.67	33%	
		Avg ROG/NOx	**0.44**	**44%**	
		Yield	**(0.02/0.44)**		**5 %**

Why didn't our emission reductions in Fresno result in ozone reductions?

- We can't ignore global background, circa 0.035 ppm world wide
- In the table below, we have removed a global background from all three areas
  - Almost no change in Los Angeles, but slightly closer to proportional or linear roll back
  - Bay Area now matches linear roll back
  - Central Valley still no change; options
    - Different "global background in the Central Valley caused by intense temperature and stagnation
    - Additional sources not being measured

Los Angeles	1 hr ozone		0.50	50%	
	8 hr ozone		**0.45**	**55%**	
	ROG		0.45	55%	
	NO_x		0.52	48%	
		Avg ROG/NOx	**0.51**	**51%**	
		Yield	**(0.55/0.51)**		**108 %**
Bay Area	1 hr ozone		0.85	15%	
(Fremont)	**8 hr ozone**		**0.57**	**43%**	
	ROG		0.63	37%	
	NO_x		0.50	50%	
		Avg ROG/NOx	**0.44**	**44%**	
		Yield	**(0.43/0.44)**		**98 %**
San Joaquin Valley	1 hr ozone		0.85	13%	
(Fresno)	**8 hr ozone**		**0.96**	**4%**	
	ROG		0.45	55%	
	NO_x		0.67	33%	
		Avg ROG/NOx	**0.44**	**44%**	
		Yield	**(0.04/0.44)**		**9 %**

Ozone tracks temperature except in summer!




MAPQUEST
W Bullard Ave
E Bullard Ave
0
1mi
1km
Figarden
N Palm Ave
N 1st St
Cal State Univ-Fresno
W Shaw Ave
E Shaw Ave
Biola Junction
117K cars,
5 K trucks
First St. EPA
Supersite
E Ashlan Ave
Muscatel
N Marks Ave
N West Ave
99
W Shields Ave
Herndon Canal
E Shields Ave
W Clinton Ave
N Brawley
W McKinley Ave
60 K cars
15 K trucks
N Golden State Blvd
N Van Ness Ave
Dry Creek Canal
Mill Ditch
168
Cincotta
Hammond
41
E Belmont Ave
Fresno
N Apply St
E Tulare St
H St
180
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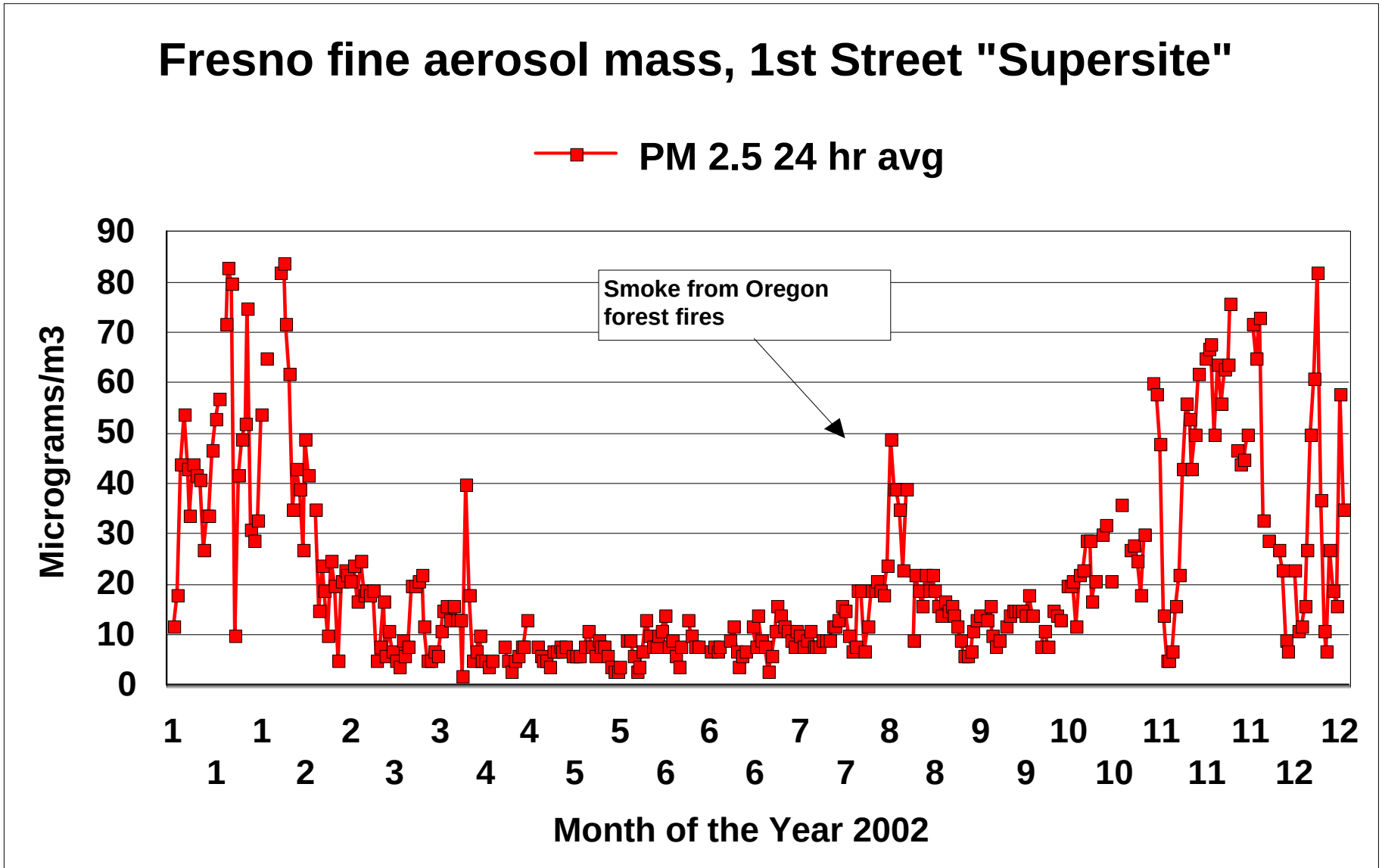
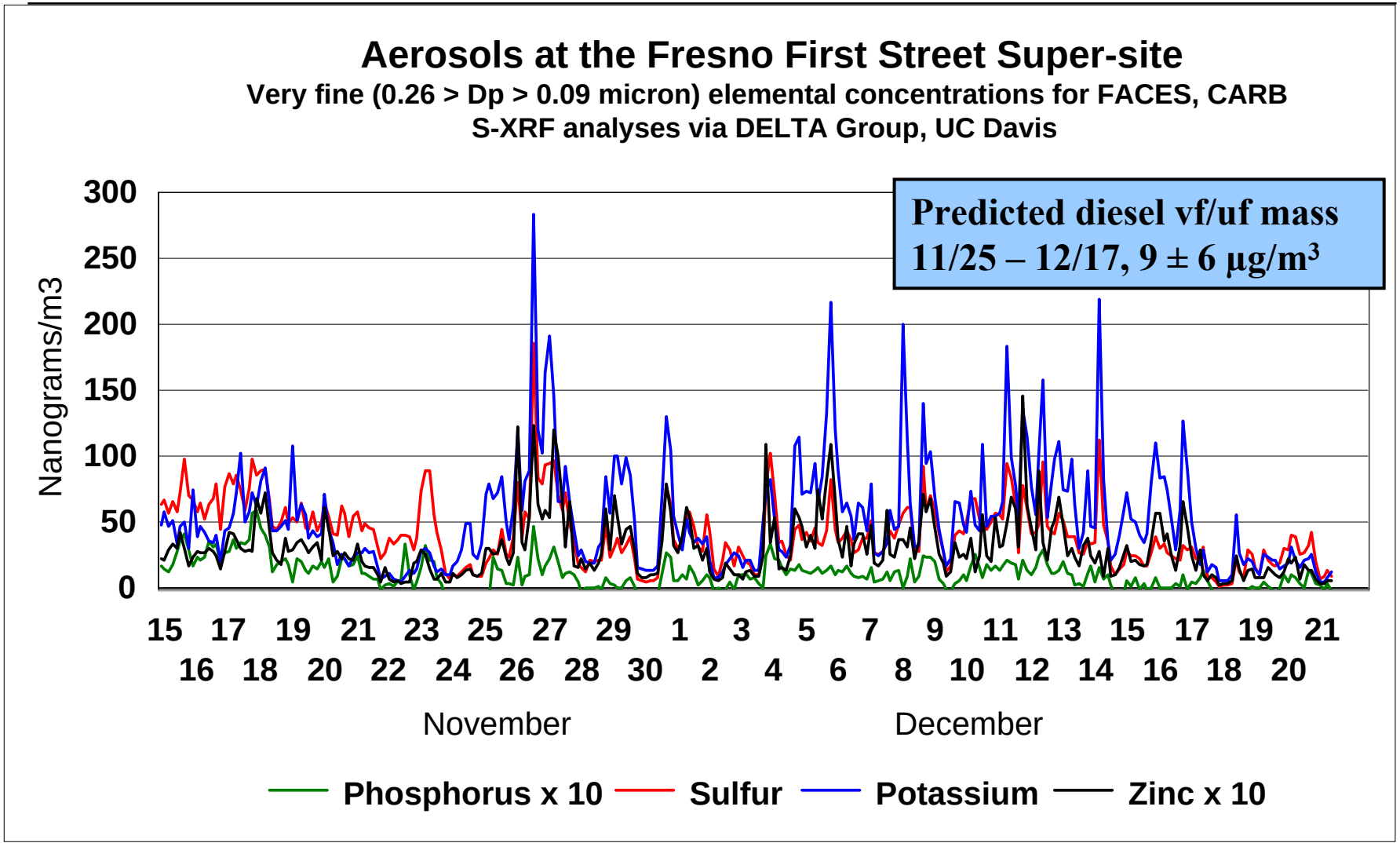
Ozone is in summer, but particles peak in winter

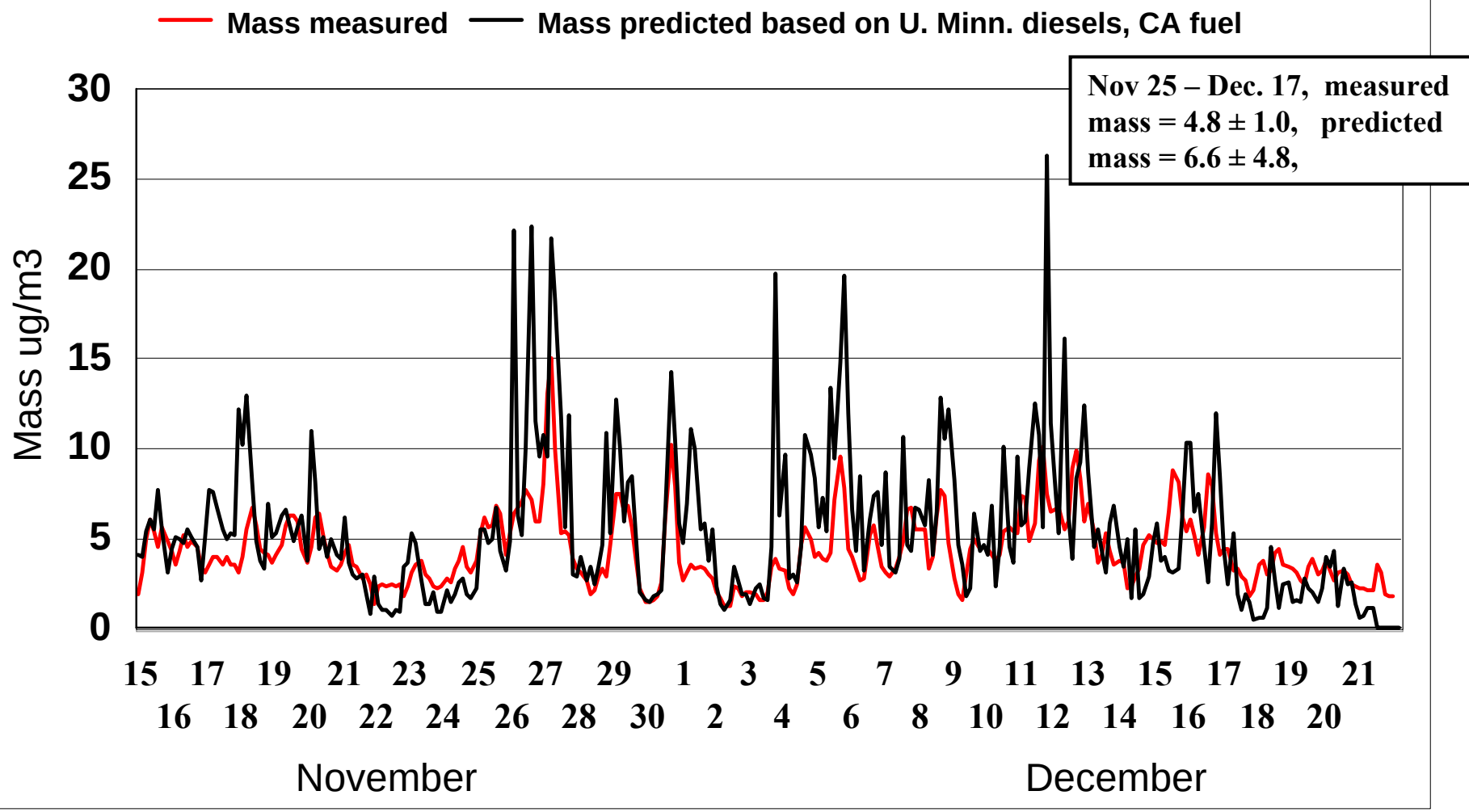


Very fine aerosols characteristic of diesels/smoking cars in Fresno > 1 km from freeways



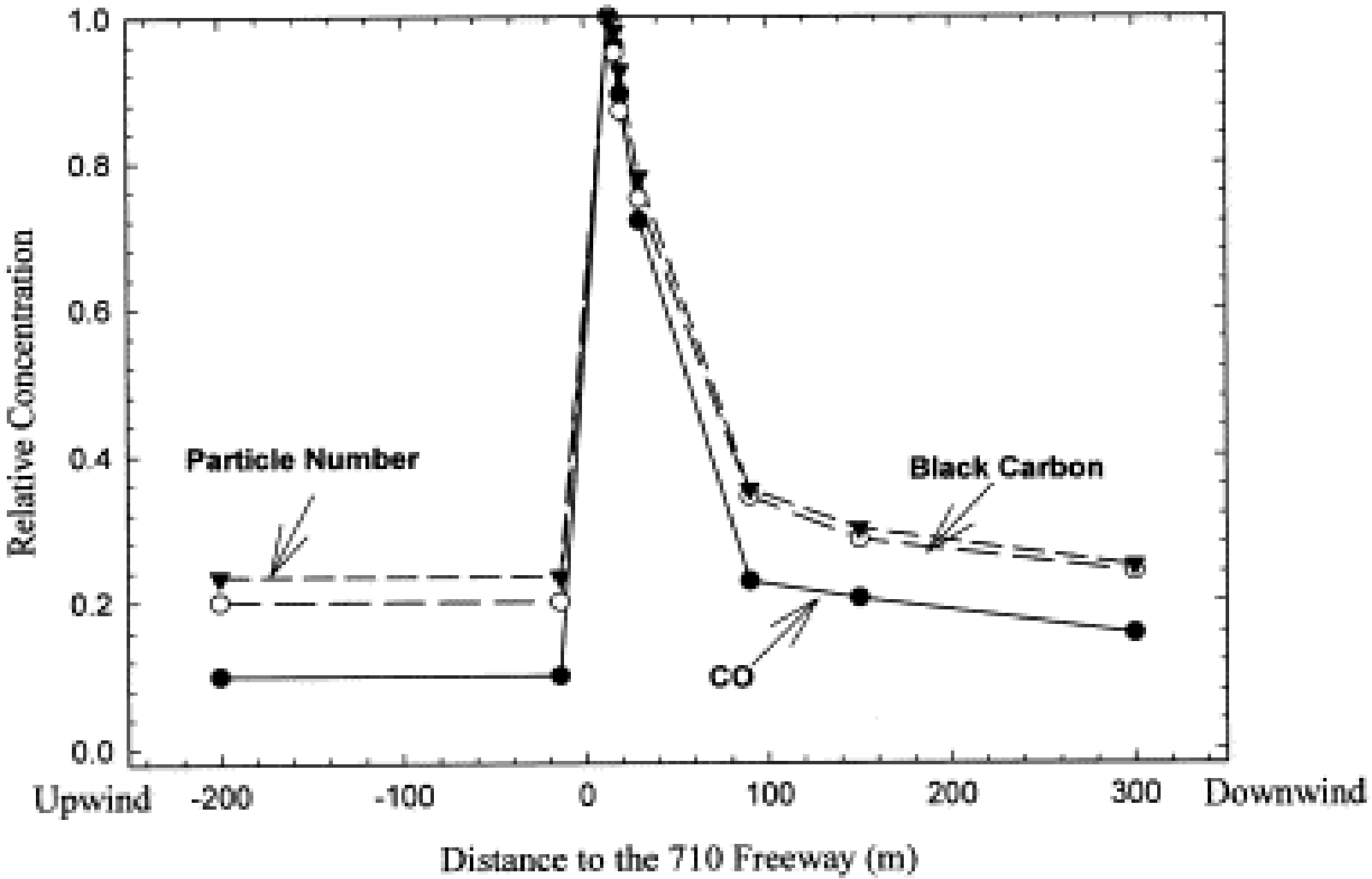
Very fine (0.26 > Dp > 0.09) Aerosols at Fresno, CA

Supersite, First Street, > 1 km from nearest freeway

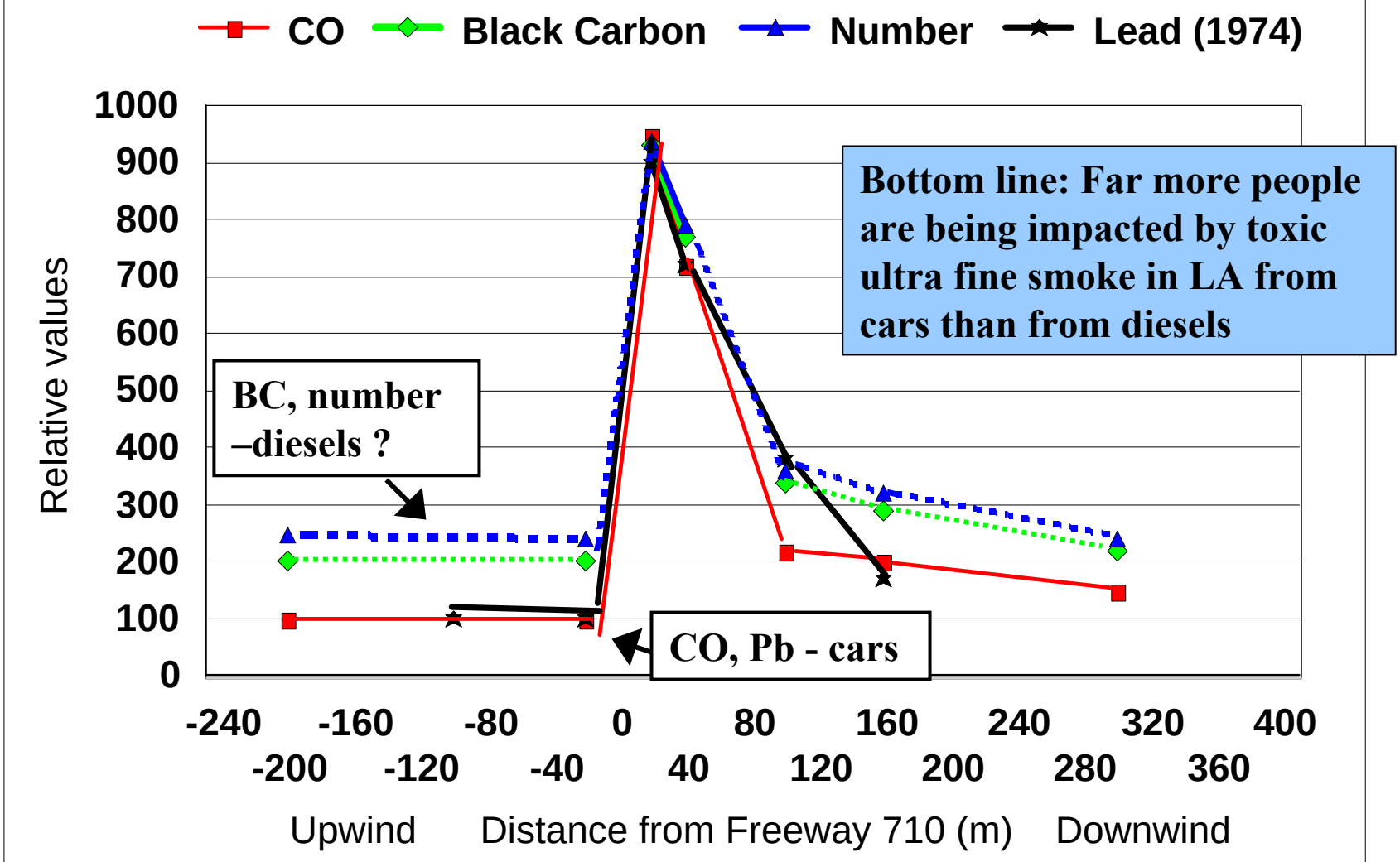


estimated total very fine mass = 8.8 µg/m^3

Study of ultra-fine particles near a major highway with heavy-duty diesel traffic - Zhu et al (2002)

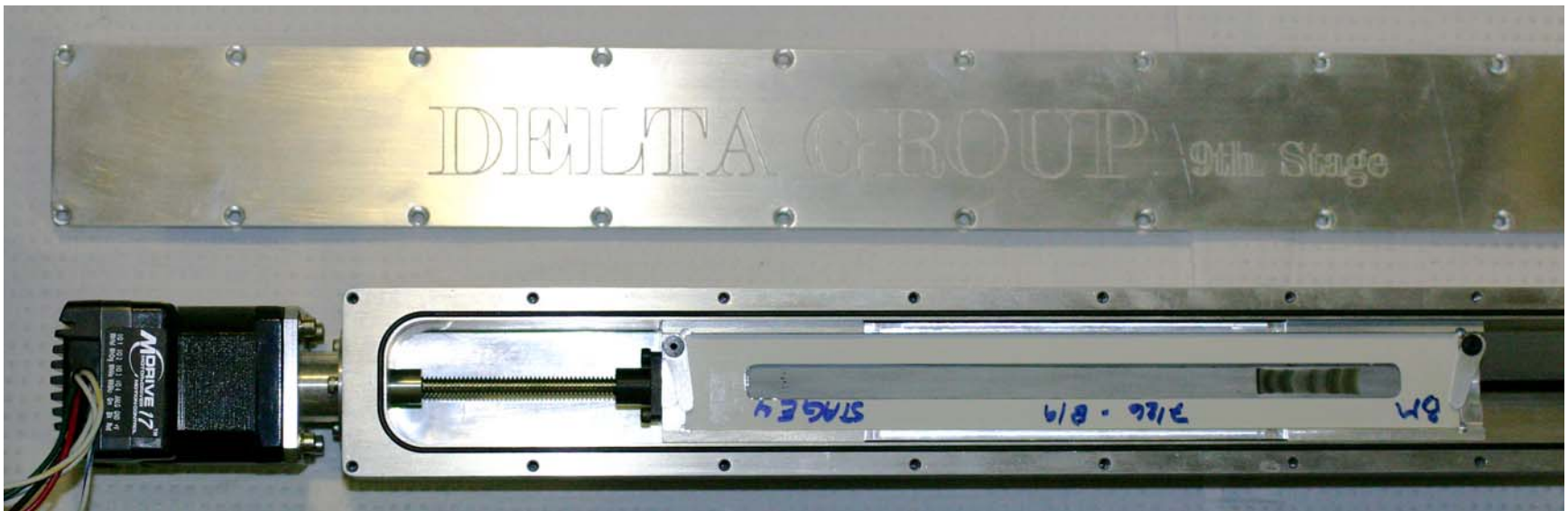


Study of ultrafine particles near a major highway
Zhu et al (2002); Lead from Cahill et al (ARB, 1974)



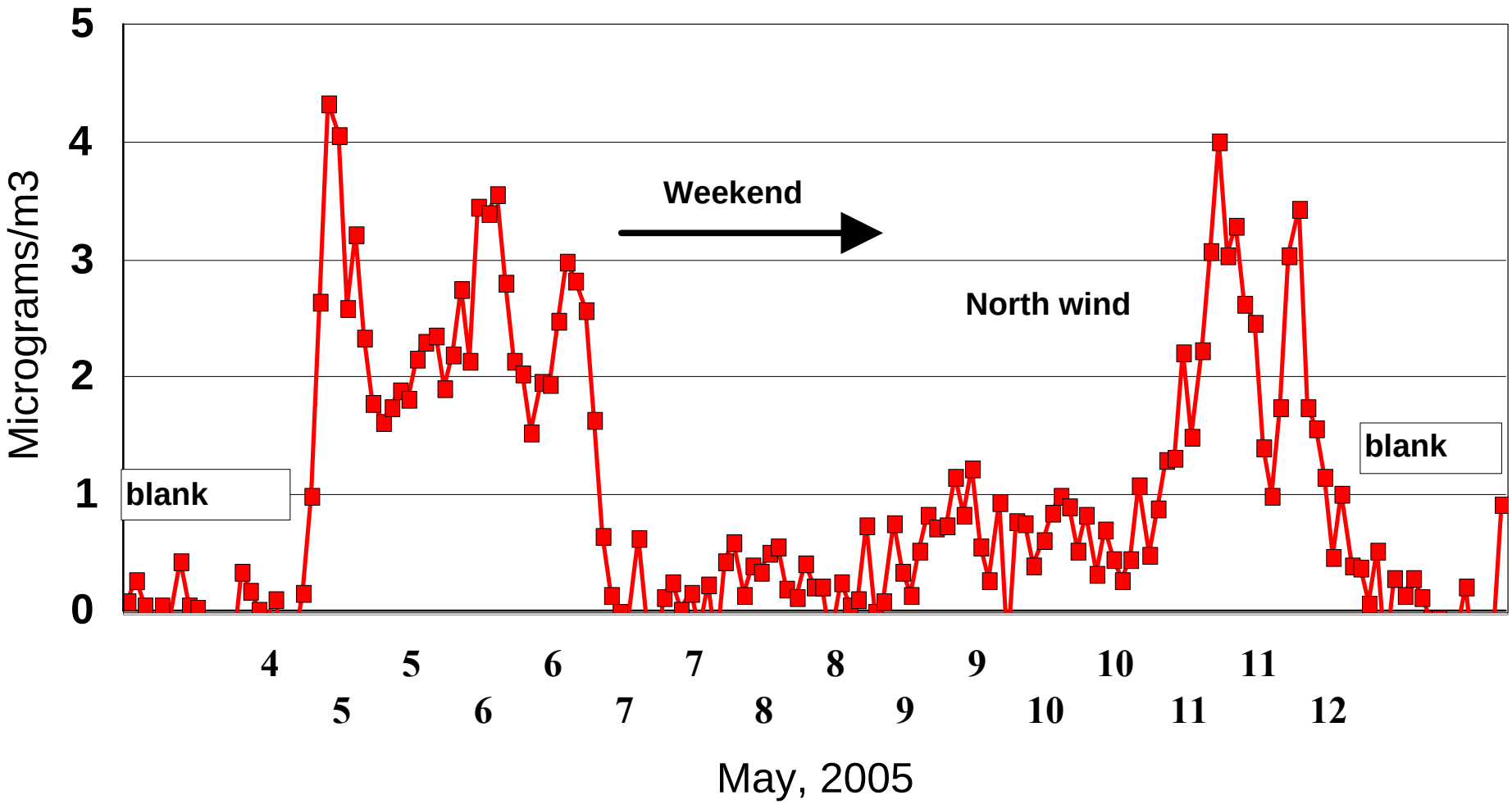
UC Davis DELTA Group Continuous Ultra-fine "Streaker" Sampler

- Mass < 0.09 μm by soft beta ray
- Elements sodium through zirconium, plus lead, by S-XRF to 0.020 ng/m^3
- Time resolution typically 3 hr



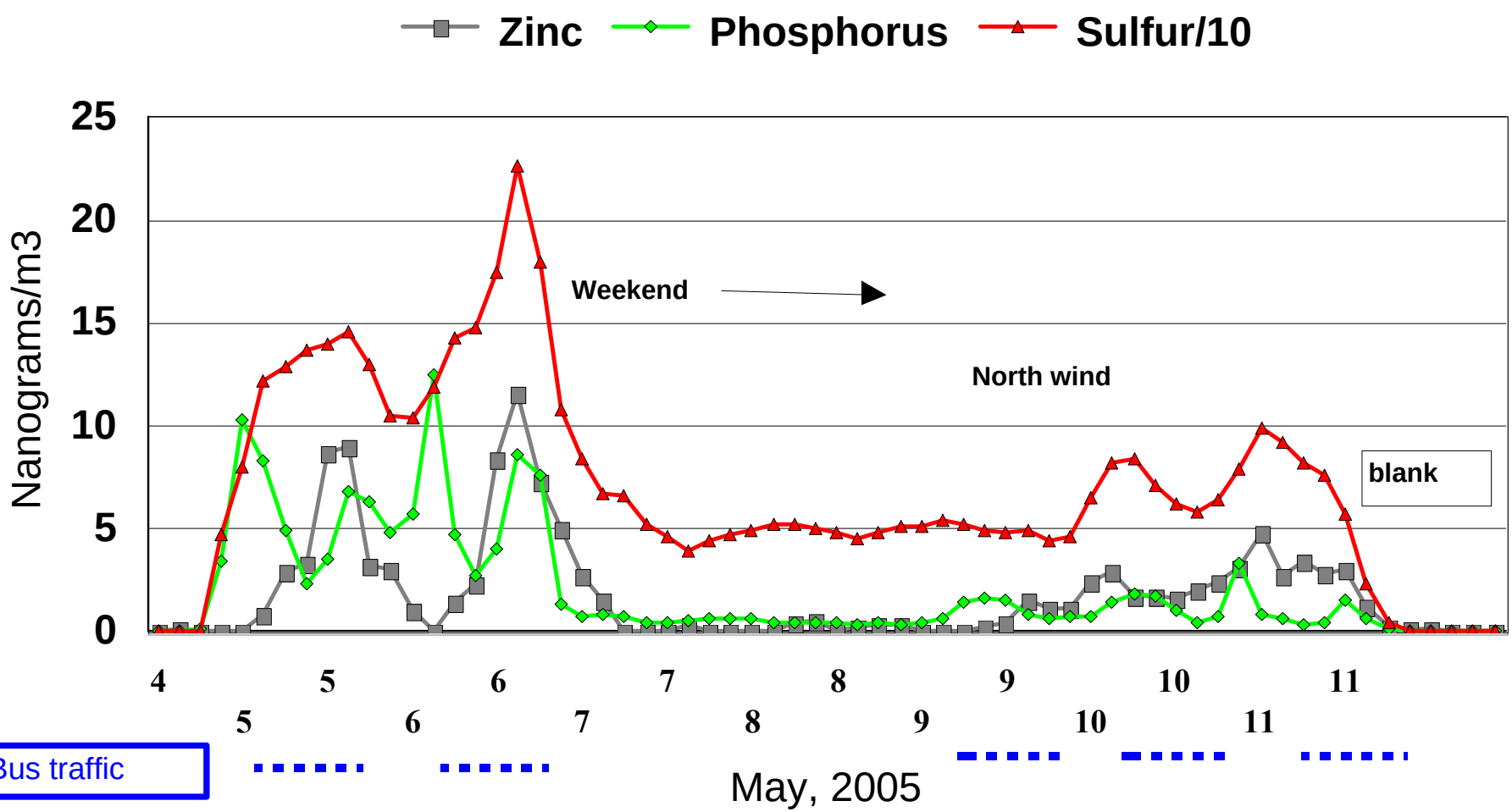
Very Fine/ultra fine particulate mass at UC Davis

0.30 > Dp > 0.0 micrometers



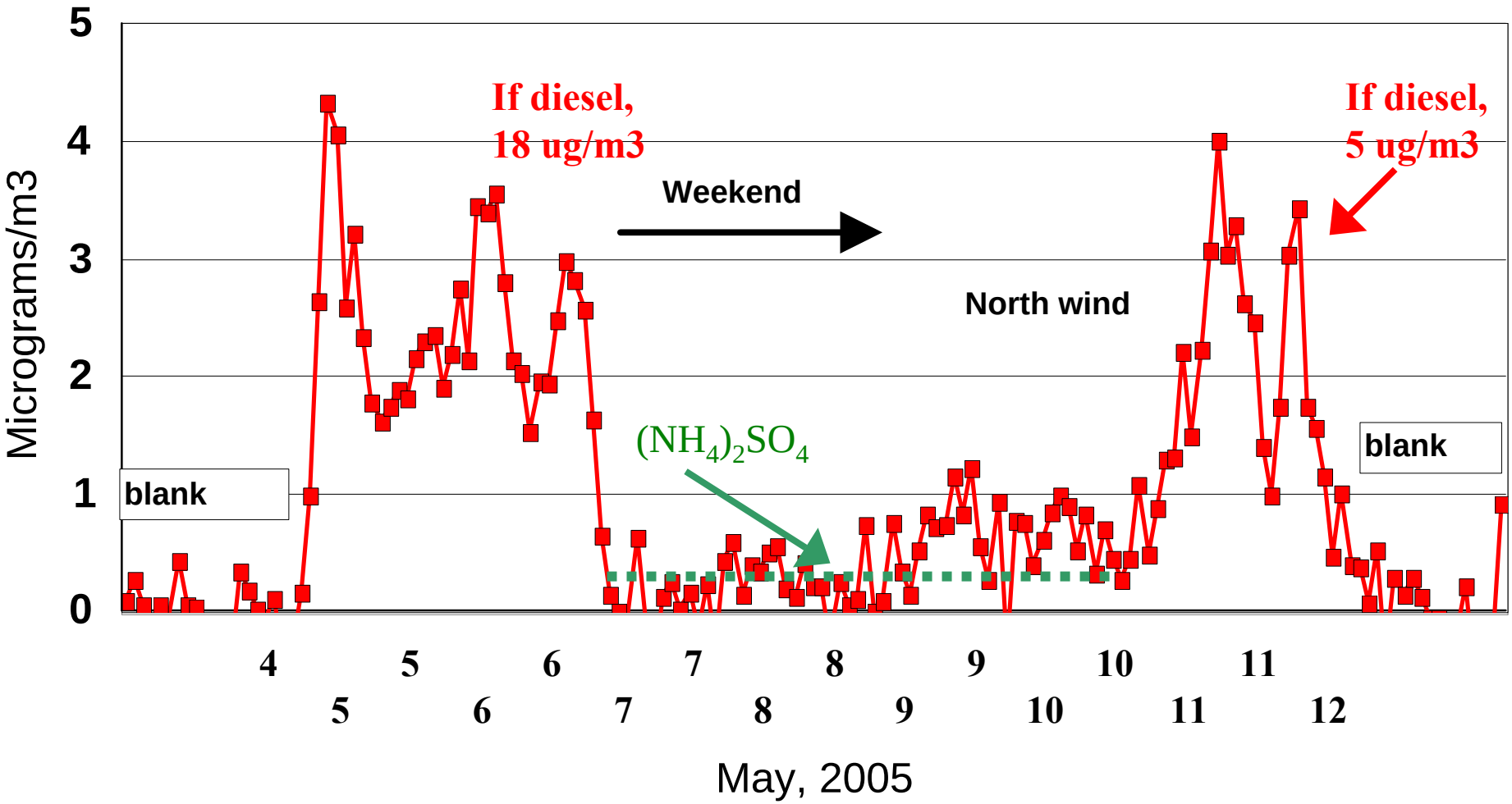
Very Fine/Ultra Fine (Dp < 0.3 micron) Aerosols, Davis, CA

Collection by "streaker" filter, mass analysis by soft beta transmision



Very Fine/ultra fine particulate mass at UC Davis

0.30 > Dp > 0.0 micrometers



Typical daytime traffic 50 m south of sampling site

Conclusions

- California has achieved splendid success in eliminating ozone precursors, and the results are a major success (except in the Central Valley)
- Very fine < 0.25 µm particle toxics are 85% of all toxic impacts (ARB Almanac + this work), and are
  - dominated by highway emissions,
  - a major problem for human health,
  - not controlled by the same methods used for ozone precursors, and
  - closely tied to partial combustion of lubricating oil.
- In most areas of California, very fine particle mass and toxics in smoke are dominated by cars, not heavy duty diesel trucks.

Suggestions?

- Focus efforts on the relatively small fraction of cars and trucks that dominate smoke emissions
  - Use smoke-enhanced on-road sensing technology
- Appreciate that it is the
  - number
  - surface area, and
  - toxicity of smoke particles

  that are more important than merely total mass.